TECHNOLOGY QUARTERLY.

EDITED BY JAMES P. MUNROE.

VOL. III. MAY, 1890. NO. 2.

WILLIAM PARSONS ATKINSON.

MEMORIAL REPORTED BY A SPECIAL COMMITTEE CONSISTING OF PROFESSORS JOHN D. RUNKLE, CHARLES R. CROSS, AND DAVIS R. DEWEY, AND UNANIMOUSLY ADOPTED BY THE FACULTY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY, AT A MEETING HELD APRIL 16, 1890.

THE recent loss which the Institute has sustained in the death of the Emeritus Professor of English and History calls for more than ordinary consideration.

Professor Atkinson was the senior of our number in regard to age, and, with a single exception, also in the order of appointment. His labors with us began in 1865, and continued unbroken until the date of his resignation, less than a year since, at the close of a half-century of teaching. He was one of the first among professional teachers to appreciate the essential truth and large importance of the radical educational ideas underlying the scheme of instruction at the newly established School of Technology, a point especially worthy of note in view of the fact that his own training, his especial professional interests, and all his associations would naturally have led him to cling to the older system of a purely classical training. But he clearly saw the importance of the new methods of education of which the Institute was the leading exponent; and so was led, almost at the very outset, to ally himself to an institution unpopular among his associates, and unappreciated except by a very small circle of his friends. And as time went on, no one watched with more honest pride and generous satisfaction its slow but certain growth to its present position.

In the work of the Faculty, our late associate bore a large and important part, — how important can be realized fully only by those who have been conversant with the inner history of our various courses of

instruction for the past twenty years. During a large portion of this time he was not only the sole distinct representative in this body of the study of the humanities, but for years he was the only instructor of any grade in history, political science, literature, and philosophy.

The many hours consumed in the lecture-room, in which he met all classes of students, and the large amount of time spent in the preparation of his routine work, laid upon him a burden which only the strongest belief in the need of such training as he gave, and the most generous readiness to render to the institution with which he was connected the best that he had to bestow, could have given him strength to carry. And, moreover, as many of us can remember, in earlier days, when students were ill prepared, often immature, and frequently very narrow in their views, the work of the Professor of English was especially perplexing and laborious.

But however great the discouragements that arose, his zeal never flagged, and by his uniform independence, honesty, good temper, and self-sacrifice he gradually brought the peculiar work of his department to be recognized by students and teachers alike as essential to the completeness of our system of training.

Professor Atkinson recognized at the outset that the character of his instruction must be peculiar, — that he must strike out in new paths, if he was to interest and instruct youth who were so receptive, energetic, and insistent on receiving practical information as those with whom he had to deal. He saw, moreover, that he could claim only a small portion of time, and still less of sustained attention, from them, since they must of necessity be quite absorbed in their professional work. And for this reason, undoubtedly, he made his lectures to be broad sketches of literature and history, rather than minute discussions of technical points or elaborate statements of the results of special researches, and endeavored by their suggestiveness, first, to interest his pupils, and, secondly, to teach them how to read, think, and judge for themselves. This end he certainly accomplished. Even the dullest and most careless student was interested in what was laid before him, and to those more competent to appreciate the instruction offered Professor Atkinson's lectures were a veritable inspiration.

Such work as this, the conscientiously performed duties of a teacher in general branches, leaves little external and material evidence behind it to remind one of its extent and usefulness. No imposing laboratory or important professional course remains as a monument of Professor Atkinson's labors. From the very nature of the case that is impossible. His memorial must be sought in the influence which his own person-

ality and the ideas imparted by him have exerted in the formation of the mind and character of his pupils. And certainly there has been no member of the Faculty to whom our graduates and other past students have confessed their obligations more frequently, or with greater uniformity, than to him of whom we speak, and none for whom they have entertained a warmer personal regard. They have always remembered his sympathy, his warm interest in their welfare, his constant readiness to help them by kind counsel, — in short, his entire friendliness to them, whether earlier, as pupils, or later, when they had entered into professional life.

And these same qualities were always observed in his relations with his colleagues of the Faculty; cheerful, conscientious, pacific, holding before himself and all others the highest moral standards, ungrudging of his time and unsparing of his labor, he did with heartiness whatever his hand found to do, and seconded every effort whose end was to build up the Institute, whether it worked for or against the immediate interests of his department or himself.

The Faculty are saddened by his loss. They will remember his labors with grateful appreciation, and cherish his memory with affection and esteem.

SOME OF THE PRESENT ASPECTS OF EDUCATION.[1]

BY WILLIAM P. ATKINSON, LATE PROFESSOR OF ENGLISH AND HISTORY.

[In the twenty-five years of Professor Atkinson's faithful service at the Massachusetts Institute of Technology, fully three thousand young men and women must have come under his teaching, and it is not too much to say that in the life of every one of these his was a lasting influence.

Many of his students were, of necessity, restless under teaching not directly related to scientific pursuits; ill prepared in literary and historical work, eager to make every moment of their Institute course of direct and tangible use, some of them could not appreciate the value of his instruction; but of the power of his personality, of his strong and elevating influence, there was, even to the dullest of them, no shadow of question. The genial smile of welcome, the intuitive understanding of boyish doubts and difficulties, the wise and helpful counsel, were never wanting.

His outlook upon life was sound and manly; there was nothing mean, nothing selfish, nothing petty, about it. Fortunate is the young man who is brought, even for a moment, into a moral atmosphere so pure and bracing as his! Fortunate are the students of the Institute's first quarter-century to have breathed this air!

How many of the alumni to-day, as they grow older, thank Professor Atkinson for showing them the right use of books! How many more of them, unable to follow the lines he pointed out, are grateful for the memory of the gentle, fine, courageous life that closed too soon!

To these, "his boys," the following paper of Professor Atkinson's will be of especial interest; showing, as it does, his views upon the immense changes in the ideas and methods of teaching which have taken place within his lifetime, and in which the Institute of Technology has been so directly concerned. It is a wholly informal lecture, somewhat curtailed, delivered by him, in 1882, before the pupils of the State Normal School at Westfield, Massachusetts. He had no thought of its publication, and, in view of the lapse of years, he would undoubtedly have been unwilling to print it. It is so characteristic of him, however, and so full of interest, that, with the authority of his family, it has been decided to present it almost as it was written, and, necessarily, without the benefit of revision and correction by its lamented author.

It should be borne in mind, in reading the paper, that it was written eight years ago, and was addressed to a special audience of future teachers. — ED.]

WHEN, the other day, I had the pleasure of receiving the invitation to address you on this occasion, and sat down to bethink me on what subject I should speak, I made an unpleasant discovery. I found that

[1] An Address to the Graduating Class of the Westfield State Normal School, June 27, 1882.

it was a great while since I had spoken at Westfield, and that meantime — as indeed many other things continually remind me — I had been growing old. I discovered that, in fact, I had become a veteran, going to address an audience for whom I ought to have some words of *gray-haired* experience. Now this part of veteran is a part I do not very well know how to play. In spite of the irrefragable testimony of the family Bible, I cannot for the life of me feel old. It is one of the privileges we teachers enjoy, that, living and working as we do among the young, we need not grow old so fast as other people. Nevertheless, however young I may be in feeling, I cannot but remember that it is now more than forty years since I, a mere youngster who ought to have been at school, was tumbled out of college with what was ridiculously called a liberal education, — tumbled out into this hard world, with hardly a penny in my purse, to scramble for a living as best I might in the capacity of a teacher. A teacher, Heaven save the mark! Why, it was at an age when boys nowadays are just leaving school to enter college, and you may conceive what the stock in trade of wisdom must have been with which I first set up in the business of educating my generation.

It was the unpleasant recollection of how many years ago that was which came over me when I sat down to consider what I should say to you to-day. It was the feeling that, whether I had it or not, I *ought* at least to have gathered since that far-off day some wisdom from experience to bestow on my younger brethren and sisters in the profession, which determined me to try to give you some of my own views of the progress of education in my time. I shall not be afraid of appearing egotistical, for I feel nowhere more at home than when addressing an audience of teachers, and for many years I have had the great and genuine pleasure of being a frequent lecturer in normal schools.

It was with nothing less, therefore, than a strong feeling of personal interest that I accepted the invitation to say a few words to you to-day, and determined to speak of some of the changes in the educational world which have taken place since I, a very green youth, first became a teacher. Of what may be called the petty politics of the educational world I have nothing to say, for I have long been out of them, though in past times I have served my turn on school committees and in the editor's chair. It is of the great secular change that has been slowly going on within my time in the whole philosophy of education that I would rather speak, — a change which, whether we are conscious of it or not, has been slowly

shifting the very foundations of the educational structure, and which can be compared in its importance only with that other great change of educational base which came about in the fifteenth century as the result of what we call the Revival of Learning. I shall begin by inquiring into the nature and extent of this change, whose progress has been about coeval with my experience as a teacher, for I have, as becomes a veteran, some views of my own about it, — views which, as perhaps also becomes a veteran, become somewhat more conservative, rather than more radical, as I grow older.

Of course, in speaking of the great change which has come over the methods and the philosophy of education, I refer first and foremost, though by no means altogether, to the potent influence of that vast new factor, modern physical science. Every great period in educational history is characterized by the predominance of some study, or some group of studies, as its chief instrument of culture. During the Middle Ages it was the scholastic philosophy. When the great Reformation of religion had forever broken the power of the mediæval Church, of which the scholastic philosophy was the educational instrument, the revival of learning brought to the front those newly discovered treasures, the languages, the literatures, and the art of ancient Greece and Rome; and what potent civilizers these were, what an incalculable debt the world owes them, a debt of mental training and mental discipline, a debt of refinement and elevation and enlargement of mind, is obvious to the most superficial student of history. But no one who watches the signs of the times can fail to see that the period of the predominance of classical studies has fully come to an end, and that we are fast entering upon an entirely new phase of educational development. Let us inquire what connection it has with our own educational history.

When our fathers emigrated to this country and laid the first humble foundations of our higher institutions of learning, they were concerned to provide first and foremost for the deepest of all human interests, — for that interest a care for which had led them to brave the perils of the wilderness, — the interest of Religion, in that form which they conceived to be the only true one. This once provided for, their only conception of the higher education was, as was inevitable, the conception they had brought with them from the Old World that a liberal education, so far as it was not religious, could be based only on the study of the Greek and Roman classics. Just as their religious creed was the legacy of the great Reformation, so their conception of the higher education was the legacy of that revival

of learning which was coeval with it. This higher education, too, was in their old home the monopoly of privileged classes: first, of the clergy, the only educated class of the Middle Ages; next, of the lawyers; and finally, when medicine had outgrown the control of barber surgeons and old women, of the doctors. Along with these in the home from which our fathers came were to be reckoned, by virtue of their feudal rank, the titled aristocracy who in their youth resided and were supposed to study at Cambridge and Oxford.

At first it was hidden from their eyes that this fifteenth century scheme was to prove altogether inadequate and unsuitable to the wants of the giant young republic they were unconsciously founding. In entire good faith they set to work to lay the foundations of their future Oxfords and Cambridges on the good old pattern; in good faith they endowed, in the good old way, the future Etons and Harrows and Westminsters which were to supply them; let us be thankful to our fathers for their generous care for learning. New England owes them a debt for the founding, in their day of small things, of her colleges and academies, which can never be repaid. These are what more than all else have given to New England her intellectual supremacy. To expect their founders to anticipate all the educational wants of the coming generations would be to expect a miracle. And yet they did partially anticipate those wants; for side by side with this old-world provision for the higher learning they planted the free common school for the education of the people. True, they were not free from that class bias which distinguished between the aristocratic and the plebeian in education. It was not till long after that a younger than any of the New England States ventured boldly to incorporate her University into her public school system. The aristocratic distinction of caste long hung about New England. The attempt is still made to galvanize her old academies into new life, and to make them the exclusive feeders of her colleges, — her common high schools are still looked upon in some quarters as belonging to an inferior order. I do not think that any one nowadays goes quite so far as that sturdy old Tory of a hundred years ago, Dr. Johnson, and is of opinion that it is not right, as he says, to teach reading beyond a certain extent in society. A hundred years has carried us beyond that, but plenty of Tories may still be found who doubt whether it is quite right to incorporate the higher education into our public school system, — whether the common people in their common schools have properly anything to do with culture.

On the other hand, a new principle has been steadily gaining ground among us, and that is, that in a republic like ours the higher and the highest education equally with the lower should be the care of the whole people and open to the whole people, — that this distinction of caste in education, this gulf between privileged and unprivileged, aristocratic and plebeian, is as much out of place in our educational as it is in our political arrangements, — that the higher education of a republic can no more be permanently managed rightly by sects or cliques or close corporations than can her politics, but is equally to be the care of the nation, — and, furthermore, that that higher education can no longer remain the monopoly of a few so-called learned professions. What marks the period of my experience in teaching seems to me to be just this struggle between the old and the new principles, the old principle steadily losing ground, the new principle steadily gaining. There has been, for instance, during that period a steady growth and progress in our public high schools, a steady decline in the relative importance of endowed academies. Colleges flourish in our land just in proportion as they partake of the new spirit of the times; and new instrumentalities, such as normal schools and technical and scientific schools and colleges, have come into being, which in my judgment have a great future before them.

In education we are everywhere encountering absolutely new wants, are face to face with absolutely new problems. How shall we meet them? By overturn? by revolution? by denying all the principles on which our fathers built, and ignoring all that we have inherited from them? Thus the mad French Revolutionists began with a new Year One, and set up a new worship of the Goddess of Reason. Thank Heaven, that is not the Anglo-Saxon way! The Anglo-Saxon way, when the inevitable progress of time brings some new element into the social problem, is to ask what is the minimum of change which it requires, — is to assume that we solved the problem correctly as far as our light went. If now a new factor appears, let us thankfully accept the correction it requires, thankfully adopt this new approximation toward an accuracy that can never be completely attained, but let us not in our haste say that wisdom was born with us, and that all that went before us is error.

It is this position that I have maintained from the outset in regard to that controversy of ancient classics *versus* science, a controversy which really lies very near the heart of all our educational discussions. If in mentioning this controversy I seem to you to bring up a threadbare subject, and one on which I have uttered myself by voice and in

print many times before, it is because I think it is a vital question, — a question that must come up again and again till we all reach a final agreement. Let me try, in a few words, to give you my idea of the point at which the discussion stands at the present moment.

The so-called classical and scientific question is only the name of one branch of a much deeper controversy which covers the whole ground of life and education, — it is but one phase of the struggle between Humanists and Realists which began in the fifteenth century. There are two, and only two, great divisions of studies, in one or the other of which all branches of human knowledge may be included, — the study of mind and the study of matter. How vain it is to attempt to form a complete education out of the exclusive study of either of these can best be learned by observing the effects of such exclusiveness on those who have tried the experiment. But the peculiarity of the educational situation of the day in which we are living is this, — that almost within the recollection of a teacher no older than myself a vast new body of physical knowledge has been poured out upon the world, which is not only of the highest importance to man's material well-being, but which furnishes a vast new field for the exercise of his highest intellectual faculties. Is it possible that an educational system organized before this body of knowledge came into existence can tranquilly move on in its old course precisely as though this new knowledge were non-existent? Let the lamentable history of some of our older institutions of learning, and the ill success of some of the new which have striven to ignore the situation, answer. Not to refer to our own experience, I lately had occasion to examine, as far as limited evidence enabled me to do so, into the condition at the present moment of those nine or ten great, old endowed schools of England which are usually, but very falsely, supposed still to represent her school education. In every instance, I found that those schools in the twenty years since I had once before attempted a similar examination through the printed evidence of a Parliamentary inquiry had flourished just in proportion as they had introduced the modern element into their teaching, while the one which had most successfully resisted it, old Westminster, was virtually in a moribund condition. I found, further, that in England new schools were everywhere growing into vigorous life without the prestige of the ancient name and the power of the accumulated wealth of Eton and Harrow. I was even led to doubt whether the great Victoria University, in the heart of busy, manufacturing, middle-class Manchester, was not rapidly becoming a far truer representative of the higher education of England than Oxford and Cambridge, with their crumbling towers and their picturesque antiquity.

But into this question of organization I will not now enter, for I want to ask a question that lies behind it. What part is this great, new factor of modern physical science to play in the education of the future? The day of the exclusive predominance of the ancient classics in our higher education is obviously at an end. Are classical studies to be abolished in favor of this gigantic intruder, or can some *modus vivendi* be established whereby the claims of both may be acknowledged? The first and crudest effort of this kind has been made in the attempt to add physical science in all its length and breadth to the old curriculum of higher study without any modification of the old curriculum itself. If the scheme of entrance examinations now in force in some of our older colleges be examined, it will be found that, while the old drill in the classical grammars is imposed on the preparatory schools and their teachers with even more than its ancient rigor, the demand is made for a show at least of elementary scientific knowledge, while the pressure of the spirit of the times has, in another direction, been so overwhelming, that the candidate once within the college doors is permitted to throw classical studies to the winds, and is given unlimited freedom of choice among all possible subjects of human inquiry. A more unlucky system, it seems to me, than this forced combination of all that is worst in the old methods with all that is most crude and superficial in the new, can hardly be imagined. It is one of those illogical compromises which mark a transition period, when the adherents of antiquated methods are slowly and unwillingly yielding to the pressure of the times, and all the more unwillingly because the adherents of the new ideas are so apt to be extravagant and unreasonable in their aggressiveness.

And extravagant and unreasonable in their aggressiveness, I myself think the adherents of modern scientific studies are often apt to be, raising thereby a needless prejudice against a cause which, taken on its true merits, has the justest and most reasonable claims on the attention of every teacher, and on no class of teachers a stronger one than on the teachers of our public schools. For this question of physical science *versus* classical studies is no question for colleges and academies merely, — it is a question which touches the best interests of all education, from the highest to the lowest. Unless we are prepared to accept the old-world distinction of aristocrat and plebeian in education, we have got to look it in the face as a part of the problem of national education, — a problem in whose right solution the humblest teacher in a village primary school has a direct and personal interest. For if I have one educational belief on which I feel more certain than on any

other, it is that sooner or later, and however far off the day may be, the education of this country will be all of one piece, constituted from top to bottom on one system, and that the only system worthy of a self-governing people, the broadest and most republican. However temporarily useful the relics of mediævalism may be, American education can never be permanently organized on mediæval, eleemosynary foundations.

Overlooking, then, the temporary confusion which reigns in our courses of study, the temporary alienation from popular sympathy of some of those higher institutions of learning which ought to be pioneers and guides in every new departure, I wish to ask what significance this question of the true place of physical science has for our public free schools; — a very momentous question, because, in my judgment, our public free schools are the foundation on which the whole fabric of American education is ultimately to rest. Now I said a few moments ago that I was myself a conservative. A teacher now for seventeen years in a scientific college, but not myself either a student or a teacher of physical science, — brought up myself by the most rigorous classical method, and for a good many years of my life a teacher of the classics, — I have had perhaps exceptionally good opportunities for viewing the question impartially from both sides, and I have come to two very definite conclusions as the result of this experience. I am persuaded, first, that the influence of modern science is bound within not a long period of time to recast and reorganize the whole method and spirit of our public school education, from the infant school upwards to the high school and the college; and, secondly, I am not less strongly persuaded that scientific studies alone can never constitute a true or a perfect education. Let me say a word on each of these points.

First, I say that the influence of the modern scientific spirit is bound within not a long period of time to reorganize the whole method of our public school education. And this I believe for two reasons, and I will give you the less important first. The less important ground for the immediate recognition of physical science as a far more important factor in our system of public school study than it is at present, or than it has heretofore been, is its overwhelming practical importance to the material interests of this great and growing country. Why, our public schools are not doing a tithe of what they ought to do in helping to develop the material interests of the country. Those material interests have grown into such vast proportions, — manufacturing, mining, commercial enterprises are carried on upon so vast a scale, — our

railways and telegraphs, our great Western farms, our mines of minerals and of coal, our great and ever-growing manufacturing interests, — I would add the interests of our maritime commerce, if a stupid and false economic system, a monument of our popular economic ignorance, had not destroyed it, — I say all, or almost all, these great interests are expanding into such gigantic proportions that it becomes a question of the greatest importance what our public schools are doing for their furtherance. It is too plain for argument that the well-being of the country requires its scientific education to keep pace with this gigantic development of its physical resources.

Now for seventeen years I have been one of the examiners of candidates for admission to the scientific college in which I teach. I have only just come from sharing in the examination of one hundred and fifty such candidates of the average age, as I found, of a little more than eighteen years. And these candidates have come from high schools and academies in all parts of the country. The papers we have been examining are set to test the qualifications of these eighteen-year old candidates for entering on a course of scientific study as a preparation for taking responsible positions in practical life, such as require a preparation of scientific knowledge, — as chemists, as architects, as mining, mechanical, and civil engineers, as naturalists, and last, but not least, as practical men of business to superintend and guide manufacturing and commercial enterprises. What is the story that these papers teach us? Is it that our public school system, from the primary up to the high school, is thoroughly organized as it should be to meet this great practical want of the nation? Do our examination papers show us that there is a practical vitality in the elementary schooling of our boys and girls at all corresponding to the immense vitality of the practical life of the country into which they are so soon to enter? I wish I could answer in the affirmative. Nothing is further from my purpose than to underrate the value of our public schools even as they are, and I am not unconscious of the progress they are constantly making. How can their importance be overrated! Believe me, they are the sheet-anchor of this republic. If we lose them, if we neglect them, if we are unfaithful to them, we shall forfeit our free institutions. I think nothing less than this can be said of our public schools.

And for this very reason I cannot look without alarm at the way in which just now they lag behind the demands that may justly be made on them. No, our examination papers do not tell the story they ought to tell of practical efficiency in our public school system

on the side of elementary science teaching. We cannot get what we have a right to demand on the part of young men and young women of eighteen from our public high schools, much less from our classical academies. More than by all other causes we are crippled in our own work by this want of preparation. We are forced to do the work of the schools, and begin with giving a belated instruction in the first principles of science. Many, I might say most of our students, have to begin with us at the very foundations of science, by training their eyes to see and their hands to manipulate in our laboratories, and by laying over again more firmly that foundation of mathematical knowledge without which no firm scientific superstructure can be built. And this can only be done, without overtaxing them, by sacrificing to a great extent those general studies which at the age of eighteen they ought to be pursuing, and might pursue if only their scientific preparation had been better. I speak from much experience here, for the sacrifice has to be made in the direction of the studies which I teach.

What should a youth well trained in our public schools know at the age of seventeen or eighteen, if our public schools were all they ought to be? I say, that the work of scientific teaching which we are to carry on ought to be begun in the *primary school*, not by us. I say deliberately the primary school, and I add that the grammar school should continue it. It is as absurd that the high school should have to begin the work of science teaching as that we should have to begin it, as practically with many of our pupils we really have to do. For what after all is elementary science teaching? Is it the cramming of hard Latin and Greek technical words? Is it teaching children something about a lot of complicated and costly apparatus, electrical machines, and galvanic batteries, and strange chemicals that make explosions and bad smells? Such is an ignorant man's view of elementary science teaching, and he holds up his hands in amazement at the thought of subjecting the minds of children to such a strain, as he calls it, and gravely talks of the excellence of the good old Three R's, and buttons up his pockets tight when he thinks of the batteries and the chemical smells. The schools cost too much now, he says, — he 'll pay no bills for scientific gimcracks. And if the ignorant tax-payer were right, I should entirely agree with him; but in elementary science teaching such as I mean, the museum may be collected in the fields and by the wayside, the supplies can be bought of the village apothecary and the village grocer, and much of the apparatus can be whittled out with a jack-knife. What the ignorant tax-payer just now needs to learn is, that the most expen-

sive of all schools are just the schools which teach nothing but the Three R's; that the Three R's must indeed be taught, and taught thoroughly, but in order that they may be taught thoroughly something else must be taught with them; and that that something else is neither a smattering of Greek and Latin grammar on the one hand, nor a smattering of knowledge of costly scientific gimcracks on the other, but some adequate and just rudimentary conceptions of this wonderful world we live in. How to get that sort of knowledge into the child's mind, how to get that sort of teaching into primary and grammar schools, seems to me to be the most pressing educational problem of the day.

Now I have put this question of elementary science teaching upon the low utilitarian ground of its mere practical importance, of its money value, but the question can be argued upon much higher ground than that. Elementary science teaching has got to be introduced into our primary and grammar schools because physical science is an indispensable instrument for the development of the youthful mind, and therefore a true educational philosophy puts it there. Nothing is more absurd than the stupid and ignorant talk of stupid and ignorant people about the supreme excellence of the Three R's as instruments for the development of the youthful mind. The schools that confine themselves to the teaching of the Three R's, — and I will add to them that study which we are pleased to call English Grammar, — I say, the elementary schools which confine themselves to these studies on the plea of simplicity and thoroughness are really doomed to a career of impotence and barrenness, for their theory is directly contrary to the first principles of a sound educational philosophy. What is the divinely appointed instrument for the development of the powers of the youthful mind? Leave the child at liberty to answer the question as his nature prompts him, and you will soon know. You will find that Nature herself has appointed that it shall be the wonder and the mystery and the beauty of this wonderful and beautiful world in which we find ourselves, — a wonder and a mystery and a beauty that are stimulating his intellect and his feelings through every moment of the child's waking life, — unless by our false education we succeed in dulling all his natural sensibilities and destroying his natural curiosity. Is it a very hopeful way of helping in this divine education to shut Nature out of the schoolroom, and imprison the poor child in four bare walls with nothing but a spelling-book, a slate, and a grammar? But this is the good old method of the Three R's which has come down to us from days when science was unknown, and when books were held in such awe that a

knowledge of the art of reading was able to save a man's neck from the gallows. I am afraid that surer justice would be done nowadays by pardoning those who did *not* know their letters.

I say it is this superstition that education consists solely in book learning, and that schools have solely to do with books, that more than all things else hinders our schools from attaining their full measure of efficiency. We must emancipate ourselves from pedantry, we must learn that, though it is a good thing to teach children to read, it is a far higher thing to teach them to *think*, and that the two do not always go together. So far from that, the school organization may be so perversely and ingeniously wrong, that the reading of books may become a barrier in the way of thinking; so that the more the child studies books in school, the less he will know to any good purpose, the less and not the better prepared he will be for the real work of life. It is a sad thing to say, but I think this condemnation must be passed on much that we now call school education, — that it is a thing to save a child's mind from, if he is ever to be good for anything afterwards.

To my mind the situation seems to be this. A great and precious body of new knowledge respecting the laws that govern the material universe has been added to the world's intellectual treasures almost within the generation to which we belong; the intellectual current of the age runs strongly in the direction of scientific investigation; science imposes its methods on all the domains of thought; it is the educating instrument of our time, even as the new-found classics of Greece and Rome were the educating instrument of the times of the Revival of Learning. And it is met in some quarters much in the same way as they were. You have heard of the venerable, conservative ecclesiastic of the fifteenth century who preached to his flock in this way: "There is a new language, my children, called Greek, which some pestilent fellows are recommending to us. I bid you beware of it. It is the language of the devil, and whoever meddles with it is likely to go straight to hell." Such would seem to be the view of the venerable conservatives of our day respecting modern science. It is irreligious, it is atheistic, it unsettles the foundations of faith, — let us keep to the good old ways and go on mumbling our grammars. But the world never stands still. Each age has its own educating instrument, and the chief instrument of our day is that great body of new scientific knowledge which is its own peculiar product.

I have thus tried to do justice to the scientific movement of our day as a factor in education. Let us now turn for a few moments to the other side. Is there not danger as well as good in that movement?

We need have no sort of fear, it may well be said, for the future of scientific education in America. The needs of this new country for that kind of knowledge to help in developing its vast material resources are so great and pressing that its future is secure. Does not the danger lie in the other direction, — that literary studies will be carried away by this rising tide of science, and so our education will get too strong a materialistic bias? I will not deny that I think there is such a danger, and I will introduce what I have to say on this point by giving myself the pleasure of quoting a characteristically eloquent, though characteristically extravagant, passage from Mr. Ruskin.

"The great mechanical impulses of the age," he says, "of which most of us are so proud, are a mere passing fever, half speculative, half childish. People will discover that royal roads to anything can no more be laid in iron than they can in dust; that there are in fact no royal roads to anywhere worth going to; that, if there were, it would that instant cease to be worth going to, — I mean so far as things to be obtained are in any way estimable in terms of *price*. For there are two classes of precious things in the world, — those that God gives us for nothing, sun, air, life (both mortal and immortal), — and secondarily precious things which he gives us for a price; these secondarily precious things, worldly wine and milk, can only be bought for definite money; they can never be cheapened; no cheating nor bargaining will ever get a single thing out of nature's 'establishment' at half-price. Do we want to be strong? we must work. To be hungry? we must starve. To be happy? we must be kind. To be wise? we must look and think. No changing of place at a hundred miles an hour, no making of stuffs a thousand yards a minute, will make us one whit stronger, happier, or wiser. There was always in the world more than men could see, walked they ever so slowly; they will see it no better for going fast. And they will at last, and soon too, find out that their grand inventions for conquering (as they think) space and time do in reality conquer nothing; for space and time are in their own essence unconquerable, and besides did not want any sort of conquering; they wanted *using*. A fool always wants to shorten space and time; a wise man wants to lengthen both. A fool wants to kill space and kill time; a wise man, first to gain them and then to animate them. Your railroad, when you come to understand it, is only a device for making the world smaller; and as for being able to talk from place to place, that is indeed well and convenient; but suppose you have originally nothing to say. We shall be obliged at last to confess what we should long ago have known, that the really precious things are thought and sight, not pace. It does

a bullet no good to go fast, and a man, if he be truly a man, no harm to go slow; for his glory is not at all in going, but in being. . . .

"Gradually thinking on from point to point," he continues, "we shall come to perceive that all true happiness and nobleness are near us and yet neglected by us, and that till we have learned how to be happy and noble we have not much to tell even to red Indians. The delights of horse-racing and hunting, of assemblies in the night instead of the day, of costly and wearisome music, of costly and burdensome dress, of chagrined contention for place or power or wealth or the eyes of the multitude, and all the endless occupation without purpose and idleness without rest of our vulgar world, are not, it seems to me, enjoyments we need be ambitious to communicate. And all real and wholesome enjoyments possible to man have been just as possible to him since he was made of the earth as they are now; and they are possible to him chiefly in peace. To watch the corn grow and the blossoms set, to draw hard breath over ploughshare or spade, to read, to think, to love, to hope, to pray, — these are the things that make men happy; they have always had the power of doing these, they never will have power to do more. The world's prosperity or adversity depends upon our knowing and teaching these few things, but upon iron or glass or electricity or steam in no wise."

There is a half-truth in Mr. Ruskin's eloquent tirade, which in these materialistic days we must not lose sight of, — one of those half-truths in which Mr. Ruskin is so fond of dealing. It is wholly unjust to modern science to imply that its chief result is the growth of senseless luxury. The legitimate results of the growth of modern scientific study are two: first, that it affords a vast new field for the training of the human intellect; and, next, that it is so cheapening the production of material things, that it is slowly raising the mass of men out of their bondage to mere bodily toil, and giving them the opportunity to lead the lives of intellectual and moral beings. The practical result of all our modern science is, after all, only to cheapen things; but this is a very great result, because, by throwing the burden of production more and more upon the great forces of nature, it elevates the quality of man's labor, and by rendering life more easy throws open to all men advantages and privileges which were once the monopoly of the few, and a workingman can command to-day an education and a life which once a prince might have envied. With all deference to Mr. Ruskin, it *is* an advantage to us to move fast, if only we can be taught to move to good purpose and in the right direction.

And to move to good purpose no wholesomer counsel can be given

than his, that we must learn to look beyond the mere material benefits which spring from modern scientific progress. We talk very glibly of the distinction between physics and metaphysics, but who shall draw the line? We can go but very little way in our study of physical science without encountering the profoundest metaphysical problems; on the other hand, our metaphysics divorced from physics become a vain beating of the air, a spinning of cobweb theories. And so it comes about, that the last men to underrate the value of the moral sciences are the really great students of physical science, the last men to claim the domain of education as exclusively their own. The true spirit of modern science is a reverent spirit, recognizing, even when it penetrates farthest beyond the old boundaries of knowledge, the vast and infinite realm beyond, which no finite mind can ever comprehend; the spirit which moved Newton to say that he seemed to himself but as a little child picking up shells and pebbles by the shore of the vast ocean of truth, the spirit which moved Faraday to humble and reverent worship, the spirit which made Darwin as cautious and truthful as he was profound. We can never end with the study of matter; to the study of matter we must add its complement, the study of man, the study of mind. What shall I say of this other half of the domain of thought, — the domain of what I have called historical or moral studies? The term *literature* is so vague and misleading that I do not like to use it.

Here too I have to note a great deficiency, a sad lagging behind on the part of our school system, a failure to meet the needs and the demands of the spirit of the age. We have not yet emancipated our schools from mediævalism, made our school studies the true representatives of the atmosphere of thought in which we live. In saying this, I blame no one. So far from that, it seems to me the progress we are making is as great as could reasonably be expected. The school system of a free country can only represent the average intelligence of the country. Its aim is not to raise up a literary caste, separated, as in Germany, by a great gulf from the unintellectual life of the people that surrounds it. It is far better that a nation should educate itself, even if it educates itself slowly, than that its education, whether higher or lower, should be taken in hand by a paternal government, or by a caste of book men and *literateurs*. The education of a nation is a task far too great for mere bookmen. I look with most hope to those schools and institutions of learning which share most fully in the spirit of the nation, — which have grown most directly out of its wants, and are in closest sympathy with the social organism

of which they form a part. Their progress may be slow, their work may be modest work, but every particle of it tells.

Now, when we survey the domain of what I have called roughly historical or moral studies, — by which I mean the whole of that group relating to man, his thoughts, his feelings and actions, as distinct from the study of the laws governing this material universe which forms the stage on which his mortal life-drama is enacted, — I am forced to note the defect that here too our schools are not yet emancipated from that spirit of bookishness, that spirit of pedantry, which has come down to us from the times when an impassable gulf lay between the unlearned and the book-learned. Whether we choose to recognize it or not, that gulf has disappeared. There are no longer any privileged literary classes; the ancient badges which distinguished them, the masterships and the doctorates, have become almost unmeaning; the work of which they used to have the monopoly is now oftener done outside than inside their sacred walls. The most learned history of ancient Greece written in England in our day came, not from Oxford, but from the library of a busy London banker and member of Parliament, who had never been to Oxford or Cambridge, and who, if he had gone to either of those venerable seats of learning, would probably never have written his History. We have got to recognize the fact that a new era has dawned in the study of literature and history, as well as in the study of science, and that we teachers of literature must take a leaf out of the books of our scientific brethren, and learn to apply their methods to our own pursuits. Are we doing so, and by new methods putting new vitality into moral and historical studies? Steadily and slowly I think we are, but I am afraid only slowly. During the many years in which I have had the examining of the English entrance examination papers at our school, I note a gradual improvement in quality, a general rise in the intellectual level of the classes I have to meet. But I am almost ashamed of the papers I have to set. I cannot assume anything like that average level of literary culture which I think young men and young women of eighteen ought to attain at our high schools; much less can I assume that anything like system or logical method prevails in literary teaching. Literary instruction at present is the very realm of chaos and confusion, till it can hardly be said that any two of my students have been trained alike. I have pupils who have wasted their school time in an abortive attempt to learn Latin and Greek. I have students of the type of the thoughtful son of a country doctor, who told me that as a boy he had read and pondered the miscellaneous contents of his

father's library in the primitive retirement of his father's hay-mow, and who proceeded to show in everything he did that he had pondered them to good purpose, — that hay-mow having proved to him a true academy. I have, on the other hand, students of the type of the youth who returned to me a long list of English classic writers whose works he had been put through at a high-pressure school, naively adding, that, if there were any studies he *hated*, they were rhetoric and literature, and who forthwith proceeded to illustrate the beauties of cramming by showing that he knew nothing about his formidable list of authors.

However it may have been in the past, it can no longer be maintained that the study of the English and other living languages cannot be turned into an instrument of the strictest mental discipline. I look upon the chaos and confusion that reigns in this most important department of school work as the direct result of the influence of college classical examinations. Let these be changed by a frank acceptance of an equivalent for Greek, instead of the futile attempt to thrust all other studies into the unhappy schoolboy's course alongside of Greek, and a course of English study worthy of our high schools would instantly organize itself. Latin would maintain its place, but with a new character and added weight; the study of the living cultivated languages of the world would gain new dignity and importance as disciplinary studies; but, above all, the systematic study of the mother tongue, and all the wealth of its rich literature, would take its true position. Then the study would be organized on true principles, and the breath of life would be breathed into the dreary pedantry of school grammars. Our eyes would be opened to the truth that we are born into the possession of a language and a literature second to no other in power and beauty, — a language that more than any other seems destined to be the general instrument of communication among civilized men. One would think that its loving study ought to be found at the very heart of our school system, that it ought to be the foremost object of our educational care; but it is not that now.

Then, too, I think there will be a real chance for that group of studies which, for want of a better name, I must call historical or moral, and for which the study of language is the preparation. I do not much care to describe the condition of historical study in our schools as it is revealed to me by my examination papers. I am almost tempted to imitate that famous short chapter in Horrebow on the snakes in Iceland, and say there is *no* study of history. But then to justify such an assertion I should have to explain what I mean, for we all know that

compendiums of history are studied, and dates are learned by heart, and histories are sometimes read in our schools. Nevertheless, I think that the organization of historical studies into an instrument of real mental discipline is an important piece of educational work still remaining to be done. I wish time allowed me to state what seem to me the main factors in the problem; how it would involve the study and understanding not more of the events of remote nations and bygone times than of the events of the very day that is passing over us, and of the great moral and intellectual forces in the midst of which we live; how its foundation would be laid even in school by the study of those very forces. I am utopian enough to believe that the rudiments of governmental science, the outlines of the laws under which we live, the elements of that political economy in accordance with or in defiance of whose principles the great industries of this modern world are carried on, — I say I believe that the rudiments of these apparently formidable subjects should all be taught in school, in order that our boys and girls may grow up intelligent citizens, capable of understanding the story of the past and of taking an intelligent part in the doings of the present. That will be the true Civil Service Reform, and perhaps we shall not get it till then. But it is too late for me to attempt to work out this branch of the subject. It would require a lecture to itself.

I cannot close this very imperfect survey of the present aspects of education without noting one other great step in progress which is big with hope for the future, — I mean the admission of women to all the privileges of the higher education. When we consider how largely the education of the young, and especially the guidance of those first steps in intellectual progress which are of all others the most important, are, and always must be, in the hands of woman, there can be no more hopeful sign in regard to the education of the future than to see that woman's right equally with man's to the advantages of all the highest culture the community can give is fast being fully recognized. And it is not only in the direction of literature, but in the direction of science, that I see new hope here. Women are not only improving, they are diversifying their education. The world is discovering that there is as great a variety of talents and aptitudes lying hidden in feminine as in masculine brains. And though I am not one of those who are for confounding all distinctions of sex in education, yet I am sure of one thing, that we never shall know all that woman is capable of doing till we have given her the amplest opportunity to show what she can do. It is now some years since a young lady

wrote us from Vassar College, where she had just graduated, to say that the teaching of Maria Mitchell had interested her greatly in the study of physical science, and to ask the privilege of entering our chemical laboratory as a special student. The question of the admission of women to the privileges of our school was fought out over that young lady's application, and decided in her favor. And when the time came for the class to graduate to which she was attached, she modestly asked that she might be allowed to stand all the examinations and be considered a candidate for our scientific degree. She did stand all the examinations and received her degree, and she has ever since been the efficient head of a chemical laboratory for women, established and equipped in connection with our school by a society of Boston ladies organized for the purpose of promoting the higher education of their sex. Since then we have never been without young women in our chemical and physical courses. At our recent graduating exercises, not the least interesting or valuable paper was the account by a young lady of an original and elaborate series of chemical and microscopical investigations.

Young ladies and gentlemen who have invited me to address you, in those far-off days when like you I stood on the threshold of life, I called myself an educational reformer, and I have no doubt I was often a very rash and a very hasty one. What shall I call myself now that my hair has grown gray? Shall I renounce the title, and fall back into the ranks of the reactionaries? No: you see I call myself a reformer still, but years and experience have taught me how hard is the upward path of improvement, how slow and toilsome must be all true progress, — much labor with seeming little result, and yet honest labor never in vain. Above all, I have discovered that, if we are ambitious to be world reformers, there is but one place where we can begin the great work, and that is at home; that he who would improve others must be in constant process of re-forming himself. I would not discourage you from either task. To re-form ourselves is what we were set on earth for, and no one can honestly and patiently set about that work without bringing a blessed and wholesome influence on all who surround him. As teachers I cannot promise that you will not have many discouragements and difficulties to encounter, but there is no occupation in which you can engage where the rewards of faithful and disinterested service are higher, or where there are more incitements to a true and noble life. Will you allow me to give one piece of parting advice? Let me counsel you, as one who speaks from a suffering experience, to preserve your health, your bodily and your mental

health, — and you cannot have one without the other. The nervous wear and tear of teaching is very great; and better than much book-learning as a true capital for a teacher is the cheerfulness, the elasticity, the readiness of resource, which come from a sound body and a sane mind. Our profession suffers in no way so much as from the want of these. I cannot prescribe rules of hygiene for you. Let me only say that two great safeguards to health of body and health of mind are plain living and high thinking. And I should be untrue to my deepest convictions if I did not add, as greatest of all, that faith in God and that constant prayer for guidance without which, however little we may know about the method of its answer, I do not believe that any life can be completely sane or really happy.

THE DRY ASSAY OF TIN ORES.[1]

PART I.

BY HEINRICH O. HOFMAN, ASSISTANT PROFESSOR OF MINING AND METALLURGY.

THE tin deposits of the Black Hills, discovered some ten years since, are beginning to attract very general attention, and the question how to treat the ores to the best advantage has become a pressing one. No systematic investigation of this subject had been made until quite recently, when it was taken up by the Dakota School of Mines, and the ores tested as to their tenor and proper mode of treatment. In the assay laboratory numerous determinations were made of the percentage of black tin in the ore bodies, and of the metallic tin contained in it. The occurrence of tin in the Black Hills being different from that in other parts of the world, the usual mode of procedure had to be somewhat modified.

The object of this paper is to give the results of the writer's effort to discover the best method of assaying the tin ores in the dry way. His task divided itself under three heads, in the following order: —

1. To test the different methods of assaying purified black tin in the dry way.
2. To study the influence upon the assay of the different minerals associated with the black tin.
3. To find by what simple and rapid means the cassiterite could most effectually be freed from its gangue.

The apparatus used was that to be found in any ordinary assay laboratory (the pulp-balance being sensitive to 1 mgr.) as it was the aim to furnish quick and reliable methods with simple appliances. That dry assays of black tin have not the same degree of accuracy as wet assays is well known, but they suffice for the determinations necessary in metallurgical work. If great exactness is required, recourse must be had to one of the two wet methods, — that of Rose (fusing with sulphur and sodium carbonate, and converting the insoluble stannic oxide into soluble stannic sulphide), or that of Rivot (reducing the stannic oxide in a current of hydrogen to metallic tin, which is then readily soluble).

[1] Read at the Colorado Meeting of the American Institute of Mining Engineers, June, 1889.

The cassiterite occurring in the Black Hills tin ores is quite pure, as is shown by the following analyses[1] of lode tin and stream tin: —

Lode tin: —		
Occidental Mine	96.42	SnO_2
Tin Mountain	97.50	"
First Find	94.70	"
Stream tin: —		
Nigger Hill	92.60	"
Nigger Hill	93.00	"
Southern Hills	92.80	"

Stannite has lately been found in one locality. The cassiterite has an adamantine lustre, and its color varies from brown to black, the light varieties being rare. The minerals associated with the cassiterite that are of interest to the assayer are iron pyrite, arseno-pyrite, in a very few instances galena and blende, quartz, feldspar, mica, tourmaline, garnet, and columbite (tantalite). The sulphides occur rarely, and then always in small quantities; quartz and silicates form the gangue; columbite (tantalite), although sometimes found in the same veins, can always be separated by hand-sorting. When it has accumulated in the stream tin deposits, which occasionally happens, it remains with the purified black tin. Bismuth, copper, and tungsten, which occur frequently in the deposits of other countries, are found very sparingly.

I. The Assay in General.

Tin that is to be assayed in the dry way must be present in the form of oxide. The assay proper consists of applying in a crucible at a high temperature reducing and fluxing reagents, which bring the stannic oxide to the metallic state and convert the gangue into a liquid slag. The behavior of stannic oxide and of metallic tin at an elevated temperature causes, however, certain difficulties, which make the results often less accurate than could be desired. These difficulties are: —

First. That some of the resulting metallic tin is liable to be volatilized.

Second. That metallic tin decomposes the alkali carbonates used as fluxes, forming stannates, which enter the slag.

Third. That at the temperature required to reduce the stannic oxide, other metallic oxides become also reduced to the metallic state and alloy with the resulting tin button, and vitiate the assay.

[1] Transactions of the American Institute of Mining Engineers, Vol. XVII. pp. 595, 596.

Fourth. That sulphates are reduced, or, if sulphides are present, they combine directly with the metallic tin and carry it into the slag.

Fifth. That the gangue in the ore is always siliceous. This causes loss, as the stannic oxide, while passing through the intermediate state of stannous oxide, combines with silica and silicates.

Sixth. That stannic oxide is liable, before its reduction has begun, to combine with the basic fluxes used in assaying and form stannates. This liability increases as the quantity of the flux is increased.

Thus it will be seen that the results can be too high (as when iron enters the tin button) or too low (as when tin is carried off in the slag as stannate, sulphide, or silicate), and that all impurities should be removed, if possible, before the actual dry assay takes place. The making up of the charge must also be regulated to counteract as much as possible the bad influences of the basic fluxes.

The crucibles used in assaying tin ores are the ordinary clay crucibles, the plumbago crucible, and the porcelain crucible. The naked clay crucible has the disadvantage that the basic fluxes attack the clay and form silicates, which are liable to slag some of the tin. From the results obtained by the writer, it would seem that the material of the Battersea crucibles used by him must have been much better than that of the crucibles referred to by Berthier,[1] as no appreciable loss resulted from their use. P. Ricketts[2] recommends the lining of the crucible with chalk. This is probably to avoid the action of the basic fluxes on the acid material of the crucible, as the calcium oxide, being a strong base, protects the clay of the crucible from the corrosive action of the alkali, and thus hinders the formation of an alkali silicate. An outline of his method having been obtained from Dr. Ricketts, the lining was made from the so-called "prepared chalk" of the druggist in the following manner. The prepared chalk was mixed with water in an enamelled iron dish to the consistency of cream. It was then allowed to stand, that the coarse, gritty particles might settle and collect at the bottom. The chalk emulsion, now freed from impurities, was poured off and was ready for use. To line the crucible, it was half filled with the chalk mixture, the upper half being coated by giving the crucible a rotary motion, after which the excess of the liquid was poured off. The crucible was then placed bottom up for five minutes to drain, after which it stood for two hours to dry, and was then ready for use. The coating obtained was thin, uniform, and smooth. If the crucible be filled entirely with the mixture, and this be allowed to

[1] Traité des Essais par la Voie Sèche, Liége, 1847, Vol. II. p. 485.

[2] Notes on Assaying, 8th ed., New York, 1886, pp. 88, 89.

remain a little while before being poured off, the coating will be less uniform on the sides, part of the naked crucible will be exposed, and the lining at the bottom, being too thick, will crack when it dries. If a greater thickness is wanted than can be obtained by one coat, it can only be properly put on, a layer at a time, as above, until the desired thickness is reached. The effect of the lining was disappointing; it did not, as will appear later, prove useful, but rather the reverse.

Another highly recommended lining is one of charcoal. The fluxes do not act chemically upon it, and its reducing power makes it unnecessary to add any charcoal to the assay; a reducing atmosphere is kept up during the entire operation. Berthier[1] states that he obtained 4 per cent more tin in a brasqued crucible than in a naked one, although even then he recovered 2 per cent less tin than was present.

The following method of brasquing, which differs somewhat from any of those described and recommended in the books, proved the most satisfactory. Pine charcoal is pulverized and screened through a 40-mesh sieve; the fine powder is then mixed with molasses and water in a suitable flat dish, and kneaded with the fingers until a homogeneous mass is obtained, which, when squeezed in the hand, coheres into a lump, and has not sufficient moisture to adhere to the hand.

Different proportions of molasses — the ordinary New Orleans molasses being used — and water were tried. Molasses alone with charcoal gave a sticky, shiny mass, which cracked on the sides and bottom of the crucible as it dried; two parts by volume of molasses and one of water behaved better, only the bottom cracking; three parts of molasses and one of water gave the desired mixture.

The crucible is moistened by dipping into water and quickly removing it. It is then partly filled with the charcoal paste, and this is pressed with the fingers against the sides and the bottom, a slight excess of material being used. Then a conical wooden plug, which has been dipped in water, is forced by hand into the charcoal paste and turned round and round, the excess escaping over the edge of the crucible. A few light taps with a mallet help to make the lining more compact. The wooden plug has a mark, and when this reaches the upper rim of the crucible the plug is withdrawn with the same rotary motion with which it was forced in. It has the form of a long cone, the point being slightly flattened. Its size is such that when forced into the crucible down to the mark, the lining at the bottom will be $\frac{3}{8}$ inch thick. This thickness decreases until near the upper edge of the crucible, where it is only $\frac{1}{8}$ inch. It is then rounded off until even with the

[1] Traité des Essais, 1847, Vol. II. p. 485.

inner edge of the crucible, and the sides are polished with a strong test-tube to prevent any particles of tin from adhering, and to obstruct the filtering of fluxes through it. In drying, it is best to place the crucible upside down; otherwise the lining is liable to separate from the wall, especially if it dries too rapidly. When a little skill has been acquired, it takes four and a half hours, including the preparation of the mixture, to line fifty Battersea crucibles, half of size F and half of size C.

It will be seen that this lining is quickly made; it dries quickly without cracking, and is hard when dry. After being in the fire, it is readily removed from the crucible, which can be used again, and is so compact and hard that it is difficult to break the thin upper edge with the fingers, while the thick lower part has to be broken with the hammer.

In summing up the subject of brasqued crucibles, it may be said that, although charcoal linings are perfect from a chemical point of view, their use has practical objections because of the separating of fine tin from fine slag in the pan. The results to be described will show that crucible linings are, in fact, unnecessary.

The plumbago crucible stands between the naked and the brasqued crucibles, for while the action of the fluxes on the clay is weakened by the plumbago, the neutral character of the latter is slightly modified by the clay that binds it together. Plumbago crucibles are frequently used in the Cornish assay, but we shall see that this method is unreliable, and, as the plumbago crucible is expensive, more need not be said about it.

Finally, the porcelain crucible used by Levol has the same disadvantages as the naked clay crucible, although in a less marked degree.

II. Preparation of the Ore for the Experiments.

The more representative lode tin not being available in sufficient quantities to be made the basis of the following experiments, stream tin from the Nigger Hill district had to be resorted to. The cassiterite of the Bismarck district would have been the most desirable of all, as it is the purest. It is found in quartz, and has comparatively no deleterious minerals occurring with it. This makes the separation of black tin from the gangue simple and perfect. The other lode tins, as well as all the stream tins of the Black Hills, have a number of minerals occurring with them which are difficult of removal; for instance, garnets.

The first pulverizing of the ore was performed with the distance of ⅛ inch between the faces of the sample-grinder. The crushed ore was then screened through a 40-mesh sieve. At the second grinding the faces of the machine were brought somewhat nearer together, and the sifting afterwards repeated. The operation was continued until the ore had all become fine enough to pass through the sieve, with the exception of some mica, which was thrown out. This gradual method was used in order to prevent the cassiterite from becoming too fine, as a large amount might thus have been lost in the washing of the ore. The pulp obtained was then roasted in a muffle to decompose any sulphides and arsenides that might be present. After roasting, and while still hot, it was thrown into cold water, to make silicates, not otherwise attacked by acids, decomposable. It was also hoped that the cassiterite might thus be made more readily reducible, an expectation which the event fulfilled. The ore was now boiled with nitro-hydrochloric acid, to remove all soluble metallic compounds; this was continued until no more iron was perceived to go into solution. The ore was then washed with hot water and transferred to the gold pan, where the

TABLE I.

Passed through sieve No.	Remained on sieve No.	Grams.	Per cent.
40	60	90	18
60	80	80	16
80	100	65	13
100	..	265	53
..	..	500	100

panning was carried on irrespective of the loss of some fine tin which floated off with the tailings, giving them a chocolate-brown color. As the main object was to obtain a pure black tin, the loss was unavoidable. The panning was continued until no more impurities were visible to the naked eye; under the microscope, however, particles of garnet with a little quartz were still visible. The black tin obtained was dried and intimately mixed by passing it repeatedly through a 20-mesh screen and rolling it on glazed paper. The now uniform ore was sampled down, and the final average sample pulverized in an agate

mortar and put aside for chemical analysis. The weight of the purified black tin obtained, which was to form the basis of the experiments, was 7,968 grams. To find the size of the different particles, 500 grams were taken and screened through different-sized sieves. The result of the mechanical analysis is given in Table I.

The very brittle character of the cassiterite will be seen from this table, as 53 per cent of the entire ore passed through a sieve of 100 meshes to the linear inch, although, as has been said, the greatest care was taken to grind in such a manner as to produce as small an amount of slimes as possible.

III. Analysis of the Purified Black Tin.

In making the analysis of the average sample of the purified black tin, the Rose method was followed, as modified by Chauvenet, who substitutes potassium carbonate for the sodium carbonate commonly used. Two separate determinations were made, taking 0.5 gram in each case with 3 grams of a mixture consisting of equal parts of potassium carbonate and sulphur, and fusing in a No. 1 Royal Berlin porcelain crucible. The first sample was heated three quarters of an hour over a Berzelius alcohol lamp, and then for the same length of time over a gasolene lamp, after which the fused mass was treated with water in a beaker. Brown, gritty cassiterite now became visible at the bottom, showing that the decomposition was incomplete. The soluble potassium sulphostannate was then filtered off, and the filtrate acidulated with sulphuric acid and put aside; the residue on the filter was treated with hot dilute nitric acid, and the iron, manganese, and lime solution also kept. The residue was again fused with potassium carbonate and sulphur, but in a different way. The No. 1 porcelain crucible was placed within a No. 3 porcelain crucible, and this within a No. 6 plumbago crucible, the bottom of which had been filled with refractory material, that the porcelain crucible might be nearly as high as the plumbago crucible. The three crucibles were then each covered with a lid, and the fusion performed in a pot-furnace, heated with anthracite coal at a moderate red heat. This lasted one hour. The fused mass was then treated as before, and the resulting decomposition found to be perfect. The fusion for the second analysis was made directly in the three crucibles, and was complete in one operation. To make sure of this, the fusion was repeated, and, on acidulating the aqueous solution with sulphuric acid, the precipitate was found to have the milky white color of sulphur.

The reason that the first fusion over the gasolene lamp was not successful, although prolonged until the fused mass became dry, must be sought in the fact that the air was imperfectly excluded. By fusing in a crucible which is enclosed in others, this exclusion can be entirely accomplished; in fact, upon removing the outer lid when the crucible had been taken from the fire, but had not yet cooled, a strong odor of sulphurous acid was perceived, showing that not only had the air been excluded, but that the fusion had taken place in an atmosphere of sulphur.[1]

The analyses were both made by the usual methods for separating iron, manganese, and lime, and the results corresponded so closely that they can be expressed by a common average: —

SnO_2	86.24 = 67.84 Sn
Fe_2O_3	2.62
Mn_2O_3	0.50
CaO	0.66
MgO	trace
Insoluble	9.39
	99.41

If this be compared with the analysis of the purest crystal of Nigger Hill stream tin[2] that could be found, —

SnO_2	93.06
Fe_2O_3	3.08
Insoluble	3.90
	100.04

it will be seen that the cleaning of the stream tin, as described above, was very successful, the ore sample showing only 2.4 times as much insoluble residue as the crystal.

IV. The Assay in Detail.

The different methods of assaying black tin in the dry way may be grouped under two heads: —

A. Those which aim at finding the actual amount of tin contained in the ore.

B. Those which determine approximately how much metallic tin can be recovered by treatment on a large scale.

[1] This use of the three crucibles was suggested by Dr. W. P. Headden, Professor of Chemistry at the Dakota School of Mines.

[2] Report of the Dakota School of Mines, 1888, p. 142.

The first class divides, according to the character of the resulting metal, into methods (*a*) yielding a button of metallic tin, and those (*b*) yielding an alloy of tin with copper or iron.

Class A (a).

1. *The German Method of Assay.* — This method, as given by Kerl [1] and by Balling,[2] is as follows:—

Five grams of ore are intimately mixed with 0.75 to 1 gram of charcoal dust, and charged into a clay crucible; on top are placed 12.5 to 15 grams of black flux (or the substitute, 2 parts of potassium-sodium-carbonate and 1 part of flour), with 1 to 1.25 grams of borax glass, then a salt cover, and, finally, a piece of charcoal. The crucible is covered, heated in a muffle or a pot-furnace at a moderate, gradually increasing temperature, until the boiling has ceased, and then for from half to three quarters of an hour at a white heat. The crucible is removed from the fire, broken when cool, and the tin button weighed.

The process that takes place is simple. With the gradually rising temperature the tin becomes reduced to the metallic state by the charcoal, with which it has been intimately mixed, while any ferric oxide contained in the cassiterite will be reduced only to ferrous oxide and taken up by the slag. At a certain stage the black flux, or the flour of the substitute, becomes decomposed, the result being that finely divided carbon is uniformly distributed through the flux. This hinders any particles of stannic oxide from combining with the alkali when fusion begins, and assists the reduction of particles of ore that have not been completely converted into metal by the charcoal. The active fluxes — potash, soda, borax — combine with the gangue contained in the ore and form a slag; the neutral salt cover assists in making the slag liquid, and thus favors the collecting of tin particles and prevents prills from adhering to the sides of the crucible; the charcoal finally, being slowly consumed, furnishes the reducing atmosphere above the charge. When the reactions have taken place and the fusion has become tranquil, the different parts settle according to their specific gravities: at the bottom, the tin button; next, the borax slag; above this the salt slag; any unconsumed charcoal remaining on top.

In carrying out the assays the above method was closely followed. The crucibles were size F, of the Battersea make; the charcoal was made to pass a 40-mesh sieve before it was mixed with the ore; the

[1] Metallurgische Probirkunst, Leipsic, 1882, p. 412.
[2] Die Probirkunde, Brunswick, 1879, p. 391.

black flux substitute — 2 parts of potassium carbonate and 1 part of flour, to which 1 gram of borax glass had been added — was used for flux.

The charge melted readily, and the slag was very thin, showing when cool a smooth surface. The crucible was not corroded by the fluxes, and no particles of tin were visible at the sides. On breaking it, the salt slag separated readily from the borax slag, the former being coarsely crystalline and brittle. It had a resinous lustre, was subtranslucent, and of a dark purple color. This color must be attributed to finely divided carbon resulting from the charcoal on top. On dissolving the slag in water, a fine black slime remained. This proved to be pure carbon, and the solution showed only a trace of iron. The borax slag was vitreous, hard, subtranslucent, and olive-green. The button separated well from the slag, was white, bright, easily cut, and malle-

TABLE II.

No of Assay.	Resulting Tin.							
	Total.		In Button.		In Scales.		In Siftings.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
1	3.379	67.58	3.37	67.40	....	....	....	....
2	3.379	67.58	3.37	67.40	....	....	....	....
3	3.379	67.58	3.37	67.40	....	....	....	....
Average	3.379	67.58	3.37	67.40	0.001	0.02	0.008	0.16
4	3.380	67.60	3.31	66.20	....	....	....	....
5	3.370	67.40	3.30	66.00	....	....	....	....
6	3.370	67.40	3.30	66.00	....	....	....	....
Average	3.373	67.46	3.303	66.06	0.015	0.30	0.055	1.10

able; scrapings were not attracted by the magnet, showing the absence[1] of iron. The tin, however, did not all collect in the button, as usually happens with tin assays. Prills remained suspended in the slag, and some adhered to that part of the crucible in contact with it.

[1] Berthier, Traité des Essais, 1847, Vol. II. p. 473.

In the assays, the salt slag, the borax slag, and the lower part of the crucible were ground together and screened through a 40-mesh sieve. The scales of each set of assays were weighed together, and the fine pulp of the same set panned, and the resulting fine tin weighed. It seemed advisable to do it in this manner, because the amount of scales and siftings in the separate assays was so small that it might easily have caused an error in the results.

If the percentage of tin recovered in the assays Nos. 1, 2, 3, 67.58 per cent, and in Nos. 4, 5, 6, 67.46 per cent, be compared with the actual amount of tin present, 67.84 per cent, it will be seen that the results obtained by this method are all that could be desired. The two averages differ only by 0.12 per cent, which is also very favorable. That assays Nos. 1, 2, 3 agree accurately is mere accident. It will be seen that 67.40 per cent collected in the button, and that only 0.28 per cent was scattered through the slags and adhered to the crucible. Assays Nos. 4, 5, 6 agree within 0.2 per cent. Less tin was collected in the button than in Nos. 1, 2, 3; and the total result is slightly lower, although still very good, i. e. accurate within 0.5 per cent.

TABLE III.

No. of Assay.	Resulting Tin.							
	Total.		In Button.		In Scales.		In Siftings.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
7	3.320	66.40	3.25	65.00	....	....	....	....
8	3.310	66.20	3.24	64.80	....	....	....	....
Average	3.315	66.30	3.245	64.90	0.015	0.30	0.055	1.10
9	3.000	60.00	2.93	58.60	....	....	....	....
10	2.850	57.00	2.78	55.60	....	....	....	....
Average	2.925	58.50	2.855	57.10	0.015	0.30	0.055	1.10

To see what influence would be produced by variations of time and temperature, assays Nos. 7 to 10 were made, increasing the time to two hours with Nos. 7, 8, 9, 10, and keeping Nos. 9 and 10 hotter than Nos. 7 and 8, and these last hotter than Nos. 1 to 6.

Table III. shows that the loss in tin increases if the crucibles are left

too long in a very hot fire; the buttons, however, remaining free from iron.

Although the results in the naked crucible were entirely satisfactory with normal conditions of temperature and time, the chalk-lined crucible was now used to see what effect would be produced upon the assay. Assays Nos. 11, 12, 13 were made in the same way as Nos. 1 to 6, keeping the temperature reasonably low. No difference could be perceived in examining the crucible, slags, and button, except that the upper part of the crucible was more tarnished than with the naked one.

TABLE IV.

No. of Assay.	Resulting Tin.							
	Total.		In Button.		In Scales.		In Siftings.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
11	3.393	67.86	3.38	67.60	....	....	....	....
12	3.373	67.46	3.36	67.20	....	....	....	....
13	3.363	67.26	3.35	67.00	....	....	....	....
Average	3.376	67.53	3.363	67.27	0.001	0.02	0.012	0.24

Table IV. shows an average result which does not differ much from that obtained in the naked crucible, but the assays vary as much as 0.6 per cent.

If time and temperature are increased, the difference from the results with the naked crucible becomes much greater. See Table V.

With the exception of No. 22, all the buttons contained iron, some of the results being even then too low (Nos. 20 and 21), and others too high (Nos. 14 to 19). Apparently the lime, by entering the slag, assisted in carrying the iron into the tin. That nevertheless some tin was slagged is to be accounted for by the fact that there was not enough iron to prevent it; for metallic iron,[1] although if present in sufficient quantity it will precipitate the tin completely, if in too small amount will only reduce the stannic oxide to stannous oxide, which of course enters the slag.

Kerl[2] mentions the fact, that, by first heating with charcoal alone in

[1] Berthier, Traité des Essais, Vol. II. p. 459.
[2] Metallurgische Probirkunst, 1879, p. 483.

the crucible and then adding the fluxes, the scorification of tin will be lessened. The reason of this is apparent. If the stannic oxide be reduced to the metallic state, the fluxes then added will, upon fusion, simply assist to collect the fine particles of metallic tin into a button, and the danger that stannic or stannous oxide may be carried off in the slag is excluded. But other more powerful causes counteract the good results which might be expected from this modification of the German assay. The most important is the presence of iron in the metal.

TABLE V.

No. of Assay.	Resulting Tin.							
	Total.		In Button.		In Scales.		In Siftings.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
14	3.456	69.12	3.450	69.00	....	....	....	....
15	3.456	69.12	3.450	69.00	....	....	....	....
16	3.446	68.92	3.440	68.80	....	....	....	....
17	3.446	68.92	3.440	68.80	....	....	Average. 0.006	Average. 0.12
18	3.441	68.82	3.435	68.70	....	....	....	....
19	3.421	68.42	3.415	68 30	....	....	....	....
20	3.391	67.82	3.385	67.70	....	....	....	....
21	3.371	67.42	3.365	67.30	....	....	....	....
22	3.291	65.82	3.285	65.70	....	....	....	....

Although tin is reduced sooner than iron to the metallic state, there is no direct indication by which the assayer can know when to stop with the reduction and when to add the fluxes. If the reduction is carried too far, the iron also will be reduced and will enter the button; if not carried far enough, so that tin still remains unreduced, the main advantage of the modified method is lost. Another drawback is that the fluxes are added to the hot reduced ore in the crucible. This creates a liability to loss of ore by dusting.

In carrying out the experiments the proportions used were the same as with the regular method. The crucibles were placed in the hot fire, and, counting from the time that the ore appeared dark red, it was exposed for a quarter of an hour to a strong heat; then the fluxes were added in their regular order, and the charge heated for one hour.

The behavior in the crucible and the general appearance of crucible and slags were not different from that with the regular method. The color of the salt slag, however, was light green instead of dark purple; that of the borax slag, dark olive-green instead of the usual lighter shade. The tin buttons did not separate well from the slag, as their surface was very uneven. In some places were slight depressions or even cavities; in others, the button was covered with small beads of metal, adhering partly to it and partly to the borax slag. Some of the buttons were bright, and more or less malleable and free from iron; others, however, contained so much iron that they had not the usual white color and bright appearance, and cracked when hammered flat to the size of a dime.

Two double sets of experiments were carried out, the one in a naked crucible at a normal and then at a high temperature, the other in a chalk-lined crucible under the same conditions. The results obtained in the naked crucible are given in Table VI.

TABLE VI.

No. of Assay.	Resulting Tin.							
	Total.		In Button.		In Scales.		In Siftings.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
23	3.363	67.26	3.33	66.60	....	....	....	....
24	3.333	66.66	3.30	66.00	....	....	....	....
25	3.253	65.06	3.22	64.40	....	....	....	....
Average	3.316	66.32	3.283	65.66	0.002	0.04	0.031	0.62
26	3.484	69.68	3.460	69.20	....	....	....	....
27	3.334	66.68	3.310	66.20	....	....	....	....
28	3.259	65.18	3.235	64.70	....	....	....	....
Average	3.359	67.18	3.335	66.70	....	....	0.024	0.48

The average result of assays Nos. 23, 24, 25, carried out at a normal heat, is over 1 per cent lower than that obtained by the regular method, and there is a difference of 2.6 per cent between the highest and the lowest of the results. The buttons, however, were all free from

iron. Those from assays Nos. 26, 27, 28, carried out at a high temperature, show the presence of iron in quite a marked degree. There was no regularity whatever; No. 26 took up so much iron that the button weighed more than the tin obtained by chemical analysis; Nos. 27 and 28 also took up iron, and at the same time gave some tin to the slag.

The results obtained by this modified method are therefore unsatisfactory. They become still more so if the assay is carried on in the chalk-lined crucible. This can be seen from Table VII.

TABLE VII.

No. of Assay.	Resulting Tin.							
	Total.		In Button.		In Scales.		In Siftings.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
29	3.419	68.38	3.41	68.20	....	....	....	....
30	3.339	66.78	3.33	66.60	....	....	....	....
31	2.969	59.38	2.96	59.20	....	....	....	....
Average	3.242	64.84	3.233	64.66	0.009	0 18	....	....
32	3.425	68.50	3.390	67.80	....	....	....	....
33	3.365	67.30	3.330	66.60	....	....	....	....
34	3.205	64.10	3.170	63.40	....	....	....	....
Average	3.332	66.63	3.297	65.93	0.001	0.02	0.34	0.68

Of Nos. 29, 30, 31, made at a low temperatnre, one assay (No. 29) contained iron, and between the other two there is a difference of 7.4 per cent. This discrepancy was probably caused by the large amount of tin carried off in the slag of No. 31. Under the caption "Siftings" there is a blank. As siftings there remained in the pan a heavy brown-black slag, which, when examined in the wet way, proved to be rich in tin. The assays Nos. 32, 33, 34, carried on at a high temperature, gave buttons which were all strongly ferruginous; they also showed great irregularity. Judging from the results obtained by the modified method, — Nos. 23 to 32, — the preference must be given to the regular German method, although, as above stated, it would

seem rational to suppose that the loss in tin would be smaller if the black tin were reduced to the metallic state before the flux is added and the fusion begins.

Mitchell[1] gives a method which may be mentioned in connection with the German assay. He mixes 400 grains ore, 100 argol, 300 sodium carbonate, 50 lime, and charges in a crucible so large that it need only be half filled, then gives a cover of sodium carbonate and 200 grains of borax; heats gently, and keeps for at least twenty minutes at a dull red heat, increasing the temperature until tranquil fusion takes place.

The experiments were carried out as directed. A beautiful bottle-green slag resulted. It was as glassy as obsidian, and covered with a thin slag of a lighter green color. The results from three consecutive assays were so discouraging that no further attempts were made in that direction. Nearly all the tin had been taken up by the slag, the only apparent reason being the intimate mixing of ore and flux.

2. *Fusion with Calcium Fluoride.* — There are three methods described under this head, in all of which fluorspar is used as the only or principal flux. They are recommended for ores containing silica only.

Fluorspar is not readily fusible; in fact, it cannot be melted at temperatures produced in a muffle-furnace. Assays requiring it as a flux must therefore be carried on in a pot-furnace. While difficult of fusion, it is liquid when melted, and assists to liquefy compounds which have a refractory character, by holding in suspension the particles which cannot be completely melted. It is therefore very satisfactory if a high temperature is required. Berthier[2] was the first to suggest that a loss in weight takes place if calcium fluoride and silica are heated together. In later publications[3] the formula $2\ CaF_2 + 2\ SiO_2 = SiF_4 + Ca_2SiO_4$ is found with the statement that part of the silica escaped as silicon fluoride. Percy[4] has shown by experiments, that, while a loss in weight does take place, the formula is wrong, as it expresses more than three times the actual amount lost. It would seem, therefore, that the basis on which these methods are founded is not a correct one. Owing to the high temperature, there is always danger of losing tin through volatilization, although[5] in a char-

[1] Manual of Assaying, New York, 1881, p. 481.
[2] Traité des Essais, 1847, Vol. I. p. 436.
[3] E. g. Balling, Metallurgische Chemie, Bonn, 1882, p. 88.
[4] Metallurgy of Fuel, etc., London, 1875, p. 80.
[5] Berthier, Traité des Essais, 1847, Vol. II. p. 458.

coal-lined crucible this may be prevented by entirely excluding the air. In regard to scorification, it seems doubtful whether it can be avoided so as to give satisfactory results.

(1.) Ricketts[1] recommends mixing 10 grams of ore with 10 to 20 grams of fluorspar or cryolite. He then says: "Charge in a charcoal-lined crucible, which is first covered with charcoal and then luted with clay; heat strongly for about one hour; remove carefully from the fire, and tap gently. Treat the button as an alloy afterwards." These instructions were closely followed, fluorspar being used and the time of exposure to heat lengthened, as previous experiments in charcoal-lined crucibles had shown that considerable time is required for the heat to penetrate the lining.

Three experiments were made, resulting in a gray, slightly fritted mass, which contained white tin and black tin mixed with fluorspar. This gave, when crushed in a porcelain mortar and treated with water, gray slimes, and, as residue, the mixture of white and black tin. The complete reduction of the stannic oxide was probably prevented by the intimate admixture of fluorspar. It could scarcely have been caused by insufficient heat. A hot anthracite fire was used; the furnace was 12 × 12 inches, the crucible resting on 3 inches of coal, and being covered by 3 inches of coal (to the lower edge of the flue). The draught was strong, the total time of exposure to heat two hours.

(2.) Ricketts[2] gives a similar charge for a chalk-lined crucible: ore 10 grams, fluorspar 10 grams, powdered charcoal 2 grams, a salt and charcoal cover, and recommends a hot fire.

This method produced negative results. The charge at the bottom and sides of the crucible was fused; it was gray, showing a crystalline structure. At the bottom the fused rim was $\frac{1}{8}$ inch thick, decreasing to $\frac{1}{16}$ inch higher up. Inside this shell was a fritted mass of a color from dark gray to black, consisting apparently of charcoal and fluorspar, with fine particles of tin dispersed through it, and covered by a pumice-like gray slag, probably a mixture of salt and fluorspar.

(3.) Balling[3] recommends mixing 5 grams of ore with 2.5 grams of fluorspar and 2.5 grams of lime, charging the mixture in a charcoal-lined crucible, and treating as in the old German method of assaying iron ores in the dry way; that is, heating for an hour and a half, the last fifteen or twenty minutes at a white heat.

The result of several fusions was a slightly sintered mass of a grayish-

[1] Notes on Assaying, 1886, p. 88.
[2] Ibid., p. 89.
[3] Die Probirkunde, 1879, p. 391.

white color collected into a button. Through it were distributed prills of metallic tin of different sizes, the largest being about the size of a small pin-head. Another negative result.

No pains was spared to make these experiments with fluorspar as thorough as possible, and the failure to obtain satisfactory results must have been due to one of two things; either the ore used was not suited to that mode of treatment, or important particulars were omitted from the directions given.

3. *Fusion with Potassium Cyanide.* — This very valuable method of assaying tin ores is given by Mitchell.[1] In describing his manner of operating, he says he uses a 3-ounce Hessian crucible, rams into its bottom a ½-inch layer of potassium cyanide, adds the charge, consisting of 100 grains of ore mixed with from four to five times its weight of powdered potassium cyanide, and gives a cover of the same flux. He then heats at a moderate temperature for ten minutes, removes the crucible, taps it gently, and allows it to cool. He dissolves the slag in water to see if any reduced metal or heavy particles of the original ore are present, and says that, with ordinary care, the results are accurate to 0.5 per cent.

The basis on which the process rests can be expressed by the formula, $SnO_2 + 2\,KCy = Sn + 2\,KOCy$. Potassium cyanide, being more powerful than any other reagent, acts more quickly, and also at a lower temperature, thus reducing the volatilization of tin to a minimum. The disadvantages are its cost and its very poisonous character. The extra expense need hardly be taken into consideration, as it is very nearly counterbalanced by the saving in time, the difference being fully made up by the superiority of the results obtained. Its poisonous character requires that special care should be taken in handling it. The mortar ought to be covered with a wooden lid, having a hole through which the handle of the pestle passes, and a cloth placed over this to avoid dusting. A sponge or handkerchief should protect nose and mouth while pulverizing, weighing, and mixing the reagent with the ore. The crucible should be placed to cool under a good draught, and care taken to finish the breaking of crucibles and handling of cyanide slags before the fingers have occasion to become moist. If these precautions are observed, there is no danger whatever, as the writer can testify from repeated experience.

In the experiments the ordinary chemically pure potassium cyanide — 98 per cent KCy and 2 per cent KOCy — was first used; then the

[1] Manual of Assaying, 1881, pp. 481–483.

effects produced by the different impurities that are apt to be found in commercial cyanides were studied; and, lastly, the commercial cyanides themselves were tested. The regular method given by Mitchell was varied in different ways, to see what effect modifications from other methods would have on the reagent.

In regard to temperature and time required for the assay, Mitchell says "a moderate fire," which will keep the charge at a "steady fusion" for "ten minutes." It was found that a charge can be kept at a steady continuous fusion for twenty minutes, and the temperature be too low to complete the chemical reaction. Small globules of tin can be seen floating about in the slag, and these will not be collected into one button when the crucible is broken. On the other hand, the temperature may be raised so high that the charge will boil, and the fusion still be steady and continuous. The tin will be reduced, but will not collect into one button, and the assay will again be imperfect. The best way to regulate the temperature would seem to be the following. Begin with a hot fire, and keep it at the highest point to which potassium cyanide can be heated without beginning to boil and evolve heavy fumes. This temperature is easily recognizable after a few assays. Ten minutes is a very good average for the time, beginning when the charge is liquid and brown-red. An assay may be considered finished when the pure upper slag has become so transparent that the impurities contained at the bottom of the crucible are visible through it. The tin will then have collected into one button beneath the lower slag, and very few, if any, prills will be found.

The experiments with potassium cyanide were as follows (1 to 11).

(1.) 5 grams of ore mixed with 20 grams of potassium cyanide were charged in a Battersea crucible, size F, into the bottom of which had been rammed 5 grams of cyanide; the charge was covered with 5 grams of cyanide; time given, ten minutes.

The slag was as liquid as water. When cold, its surface was smooth, and had the shining lustre of porcelain. The crucible was not corroded, and the upper part was free from tin. On breaking the crucible, it was found that the potassium cyanide had filtered through nearly the entire bottom and blackened it, the blackness diminishing on the sides and disappearing near the top. The fracture of the upper slag was coarsely granular; it was opaque, milk-white, brittle, and soluble in water. On the bottom of the crucible was an amorphous, uneven slag; it had a resinous lustre, was subtranslucent, of light green color, harder than the white slag, and insoluble in water. It was charged with the impurities contained in the ore. The button separated well

from the slag, was white, bright, easily cut, malleable, and free from iron.

To examine the slags and lower part of the crucible for prills of tin, they were placed in hot water. The white slag dissolved readily, and the green, as a rule, separated easily from the crucible. The solution of potassium cyanide and cyanate was removed by decanting, and the pieces of crucible taken out and dried apart from the residue in the dish. Both were then crushed separately, and passed through a 60-mesh sieve. The resulting fine pulp was panned, and the siftings weighed with their scales, the slags and crucibles of one series of assays being worked up together, as the weights of the resulting buttons were close enough to justify the proceeding.

TABLE VIII.

No of Assay.	Resulting Tin.							
	Total.		In Button.		In Slags.		In Crucible.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
35	3.385	67.70	3.330	66.60	....	....	....	....
36	3.365	67.30	3.310	66.20	....	....	....	....
37	3.355	67.10	3.300	66.00	....	....	....	....
38	3.355	67.10	3.300	66.00	....	....	....	....
Average	3.365	67.30	3.310	66.20	0.005	0.10	0.050	1.00

Table VIII. shows that the average result is 0.54 per cent lower than that found by chemical analysis, and the percentage of tin in slags and crucible — 1.10 per cent — rather higher than would have been expected. The greatest discrepancy, however, in the total weights is only 0.03 gram, but expressed in percentage it amounts to 0.6 per cent. It seemed, therefore, more advisable to use 10 grams of ore, as in the next experiments.

(2.) The charge consisted of ore, 10 grams; potassium cyanide, 40 grams; 5 grams cyanide for bottom of crucible, and 5 grams cyanide for cover; crucible, size F; time, fifteen minutes.

The only difference between the first and second assays is, that in the latter the bottom was covered with a larger quantity of green slag, showing (as the crucibles were of the same size as before) a thicker

layer. In assays Nos. 35 to 38 this heavy green slag had collected around the button, filling the space between it and the crucible, and not quite reaching the top of the button, which was covered by the pure white slag. It would, therefore, seem advisable to use, for a 10-gram assay, a crucible having a larger base than the size F of the Battersea make. The button could then lie on the bottom, and be surrounded by the impure slag, the top being covered by pure white slag, which helps reduction and the successful collecting of the metal in one button. If the assays are made in the muffle, the 10- and 20-gram (or Colorado A and B) crucibles, used for lead and slag assays, might be very suitable for the purpose.

TABLE IX.

No. of Assay.	Resulting Tin.							
	Total.		In Button.		In Slags.		In Crucible.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
39	6.752	67.52	6.685	66.85	....	....	....	....
40	6.752	67.52	6.685	66.85	....	....	....	....
41	6.752	67.52	6.685	66.85	....	....	....	....
42	6.742	67.42	6.675	66.75	....	....	....	....
Average	6.749	67.49	6.682	66.82	0.060	0.60	0.007	0.07

The total average differs here only 0.35 per cent from the chemical analysis; three assays agree perfectly, and the fourth shows only 0.01 gram, or 0.1 per cent difference, which is very close. The percentage of tin in slags and crucible is half as much as that in the previous assays (Table VIII.), suggesting that the first assays, Nos. 35 to 38, might have been benefited by a longer exposure to the heat.

(3.) In assaying ores in the dry way, it has been, and still is, very common to give a salt cover. To try what effect this would have, the foregoing two sets of experiments were repeated, adding the salt.

It was found that the charges melted less rapidly and were not so thin as before; when cold, the surface of the slag was uneven and rough; the crucible was corroded, but less soaked with potassium cyanide, the upper part showing no prills of tin; the slag showed a very coarsely granular structure; it was opaque, milk-white, but some-

what dull in comparison with that of the pure cyanide. No other differences were observable.

The low results shown by the averages were startling. They could not be attributed to any action of the sodium chloride, nor to the small amount of silicate derived from the corrosion of the crucible. The salt was examined, and found to be rich in sulphuric acid; this explained the loss in tin (see Table XVI.). Fine Michigan table-salt was then tested, and sulphuric acid found to be present here also; therefore, nothing further was attempted with salt. No special advantage is apparent in its use with potassium cyanide, as the slags are thinner without it, and

TABLE X.

No of Assay.	Resulting Tin.							
	Total.		In Button.		In Slags.		In Crucible.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
43	3.266	65.32	3.200	64.00	....	....	....	....
44	3.231	64.62	3.165	63.30	....	....	....	....
45	3.226	64.52	3.160	63.20	....	....	....	....
46	3.176	63.52	3.110	62.20	....	....	....	....
Average	3.225	64.49	3.159	63.17	0.020	0.40	0.046	0.92
47	6.505	65.05	6.430	64.30	....	....	....	....
48	6.405	64.05	6.330	63.30	....	....	....	....
49	6.235	62.35	6.160	61.60	....	....	....	....
50	6.220	62.20	6.145	61.45	....	....	....	....
Average	6.341	63.41	6.266	62.66	0.065	0.65	0.010	0.10

form a better "wash" for the sides of the crucible than the less readily fusible salt. If it is to be used at all, recourse must be had to Ohio salt, which, according to the Report of the Geological Survey of Ohio, "Economic Geology," 1888, Vol. VI. p. 663, is free from sulphates, while Michigan salt always contains them.

(4.) Ricketts recommends the chalk-lined crucible for the assay with potassium cyanide. He gives the charge, 10 grams of ore and 40 grams of potassium cyanide, with half of the flux in the bottom of

the crucible and the other half mixed with the ore, then the usual cover of cyanide, to which is added a salt cover, and heats for fifteen minutes. These directions were followed, only omitting the salt cover.

It was expected that the chalk-lining would at least partly prevent the cyanide from filtering into the crucible, but no difference could be observed, the crucible being just as black as if it had had no chalk-lining.

The structure of the slag was slightly coarser; it was more uneven in fracture, and of a bluish gray color, instead of the usual pure milk-white.

The average of the results is 2.1 per cent lower than that obtained by the chemical analysis, and 1.75 per cent lower than the average of the corresponding 10-gram assays, Nos. 39 to 42. The separate assays also show a difference of 1.9 per cent, which is very unfavorable. The first reason for this that suggested itself was the possible presence of gypsum in the chalk, but no sulphates were found. There remains, therefore, only the presence of lime to account for the slagging of tin.

TABLE XI.

No. of Assay	Resulting Tin.							
	Total.		In Button.		In Slags.		In Crucible.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
51	6.648	66.48	6.625	66.25	....	....	0.017	0.17
52	6.618	66.18	6.595	65.95	....	....	0.017	0.17
53	6.458	64.58	6.435	64.35	....	....	0.017	0.17
54	....	....	....	....	....	....	....	....
Average	6.574	65.74	6.551	65.51	0.006	0.06	0.017	0.17

By a mistake in assay No. 54, the entire 40 grams of potassium cyanide were mixed with the 10 grams of ore, and charged with it. No button whatever was obtained. The bottom of the crucible was covered with a spongy, greenish gray mass, and this by the ordinary white slag of potassium cyanide. This shows the necessity of having a good layer of potassium cyanide on the bottom of the crucible, probably on account of the tendency the tin has not to collect in a single button. If the crucible is filled with a uniform mixture of ore and

cyanide, a number of small buttons will be produced mixed with the slag. If a layer of pure potassium cyanide cover the bottom of the crucible, the particles of tin will sink into it, and form on the undisturbed bottom a nucleus, around which other particles can collect, and thus take up gradually most of the tin. The effect is similar if charcoal be mixed with the potassium cyanide (see 5 to 7).

(5.) The regular method of assay with potassium cyanide was modified in the same way as the German method; i. e. the stannic oxide was first reduced by charcoal, and the potassium cyanide then added to collect the particles of metallic tin into one button. It was expected that the iron would be taken up by the potassium cyanide instead of alloying with the tin. The result was tested by dissolving the slag in water, filtering the solution, acidulating the filtrate with hydrochloric

TABLE XII.

No. of Assay.	Resulting Tin.							
	Total.		In Button.		In Slags.		In Crucible.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
55	3.223	64.46	3.100	62.00	....	....	....	....
56	3.202	64.04	1.310	26.20	1.892	37.84	See slags.	See slags.
57	3.198	63.96	3.075	61 50	....	....	....	....
58	3.198	63.96	3.075	61.50	....	....	....	....
Average	3.205	64.11	....	....	0.033[1]	0.66[1]	0.090[1]	1.80[1]

acid, and boiling to expel the hydrocyanic acid formed. It was then tested with a mixture of ferrous and ferric salt, which gave the reactions for potassium ferro- and ferri-cyanide. Another part of the filtrate was evaporated to dryness, treated with nitro-hydrochloric acid, again evaporated to expel all cyanogen, and taken up with hydrochloric acid. On adding ammonium hydroxide, the reddish-brown ferric hydroxide was precipitated, showing again the presence of iron.

In the experiments, 5 grams of ore were mixed with 1 gram of charcoal, placed in a naked crucible, size F, and heated for a quarter of an hour after the charge had become dark red; then 20 grams of potassium cyanide were added; after this thirteen minutes were required before quiet fusion was obtained.

[1] Except No. 56.

The slags had the usual characteristics of the pure cyanide, but black patches of carbon were irregularly dispersed through them. The buttons were white, very bright, malleable, and free from iron; they were however rough, and covered with bead-like excrescences of tin.

These results are very unsatisfactory. The average gives 3.73 per cent less tin than is present; it is 3.20 per cent lower than that of the corresponding 5-gram assays, Nos. 35 to 38, and 2.21 per cent lower than that of the modified German method, Nos. 23 to 25. On comparing the separate weights of the tin-buttons obtained, it will be seen that the tendency of the tin not to collect in one button is enhanced by the presence of the charcoal with which the ore had been mixed. The only result of positive interest obtained by the experiments is the fact, that the iron of the black tin, reduced to the metallic state, goes into the slag, and not into the button, as in the modified German assay.

Similar experiments carried on in a charcoal-lined crucible were equally unsatisfactory.

(6.) The same method, only using a porcelain crucible, bears the name of Levol's method. Kerl[1] and Balling[2] give it as follows: 2 grams of ore are mixed with 20 per cent of charcoal in a porcelain crucible, and heated for from fifteen to thirty minutes in a muffle; 0.50 to 0.75 gram of potassium cyanide is added, and the heating continued another five minutes. They say that the results are accurate to from 0.3 to 0 5 per cent.

It was found that it is necessary to grind ore and charcoal very fine, and that an excess of charcoal must be avoided.

Two grams of ore were mixed with 0.5 gram of charcoal, and heated for half an hour in the muffle at a good scorification temperature. The crucibles were then removed, allowed to cool, 1 gram of potassium cyanide added, and the crucibles returned to the muffle for ten minutes.

They were all blackened and somewhat corroded; the slag was of a light gray color, from the charcoal, and there was a small amount of green slag. In none of the assays had the tin collected in one button; it varied in size from a button down to a fine gray powder. The crucibles were now placed in hot water, the small buttons picked out, and the fine tin separated from the charcoal and insoluble green slag by washing. This is the uncertain part of the assay. The fine tin

[1] Metallurgische Probirkunst, 1882, p. 483.
[2] Die Probirkunde, 1879, p. 392.

separates with difficulty from the green slag. If this is entirely removed, some tin will be lost, and the resulting weight will be too low; if all the tin is recovered, some slag remains with it, and the result is too high. Thus the assayer must choose between two evils, and this causes a feeling of uncertainty. Any slight mistake is multiplied by fifty when the result is expressed in percentage. This is illustrated in Table XIII.

TABLE XIII.

No. of Assay.	Resulting Tin.	
	Grams.	Per cent.
59	1.350	67.50
60	1.335	66.75
61	1.305	65.25
Average	1.330	66.50

The average is too low, showing loss from excessive care in washing to obtain pure tin. The greatest discrepancy between the single results is 2.25 per cent. This shows how difficult it is to effect a satisfactory separation of fine insoluble slag and fine tin. During the past two years the writer has made a number of assays according to this method. The results obtained from duplicate assays only agreed well when all the tin had collected in one or more large buttons; they were never satisfactory if the tin was present in the form of fine powder. It was not discovered why in one case a button, in another a powder, should be obtained. The statement made by Kerl and Balling, that the results of this method are accurate within 0.5 per cent, needs modification, as it certainly does not apply to all tin ores. Probably those of the Black Hills contain impurities that were not present in the ores Kerl and Balling have reference to.

(7.) The last experiments made with potassium cyanide followed T. W. E. David, in his "Report on the Geology of the Vegetable Creek Tin-Mining Field," Sydney, New South Wales, 1887, p. 153. Mr. David says that at the Glen Smelting Works at Tent Hill the potassium cyanide is mixed with charcoal. The only reason that can be brought forward for this modification is, that the potassium cyanide used must have been very impure. Thus, in order to increase its reducing power, charcoal was added.

Five grams of ore were fused with a mixture of 30 grams of potassium cyanide and 1 gram of charcoal; only two thirds of the flux were mixed with the ore, one third being rammed into the bottom of the naked crucible.

Contrary to expectation, the charge fused as readily as if it contained no charcoal, and came very quickly to a quiet fusion. On breaking the crucible, no button was to be found, but only fine prills of tin disseminated through a pumice-like dark gray slag, containing irregular streaks colored black by carbon. This shows again the necessity, alluded to above, of having in the bottom of the crucible a layer of pure potassium cyanide for the reduced particles of tin to collect in and form a button.

In the preceding experiments, the ordinary c. p. potassium cyanide was used, as it seemed important that the results obtained should be based on a reagent whose composition was definitely known. But this pure cyanide is somewhat expensive ($1.90 a pound), and, to see whether its use was absolutely necessary, the different commercial grades were tested. First, however, c. p. cyanide was mixed with cheaper fluxes, such as pure potassium and sodium carbonate, to obtain, if possible, a flux which would have the same action as the pure cyanide, but be considerably cheaper. The effect produced by potassium sulphate was also investigated.

(8.) The effect of potassium carbonate on the cyanide assay was tested by fusing in a naked crucible 5 grams of ore with 30 grams of potassium cyanide, to which had been added different quantities of this flux. One third of the flux mixture was rammed into the bottom of the crucible, and the rest mixed with the ore, except a small quantity kept to be used as a cover. The average time required to complete the assay was ten minutes from the time the charge began to fuse.

The charges behaved during the fusion just as if pure cyanide had been used. The crucibles remained uncorroded. On breaking, it was found that with the increase of potash in the mixture the crucible was less soaked with cyanide; in the last assay, with 41.17 per cent potassium carbonate, the bottom was blackened only to the depth of $\frac{1}{8}$ inch. The top of the slag was, in all the assays, as smooth as with pure cyanide. The color had, however, changed; with small quantities of potash, the slag, on the surface as well as on the fracture, had a bluish tinge, which grew deeper, until, in the last assay, it became of a decided blue-gray color. The structure of the slag became more and more granular, until it was so coarse as to have the appearance of granulated sugar cemented together. Finally, with the increase of potash the

lustre of the slag decreased, while at the same time it grew harder and tougher. The buttons of tin obtained did not differ in appearance from those with pure cyanide.

TABLE XIV.

No. of Assay.	Charge.				Resulting Tin.	
	Ore.	KCy.	K_2CO_3.			
	Grams.	Grams.	Grams.	Per ct. in mixture.	Grams.	Per cent.
62	5	30	3	9.09	3.325	66.50
63	5	30	6	16.66	3.300	66.00
64	5	30	9	23.07	3.275	65.50
65	5	30	12	28.57	3.263	65.26
66	5	30	15	33.33	3.235	64.70
67	5	30	18	37.50	3.230	64.60
68	5	30	21	41.17	3.190	63.80

In Table XIV. two points are striking: first, that the amount of tin obtained grows smaller with the increase of potassium carbonate; and, secondly, that no tin is recovered in the slags or in the crucible. Both facts are probably due to the same cause,[1] namely, that metallic tin decomposes alkali carbonates, forming stannates which are not readily fusible. In fact, Berthier[2] says: "By fusing one part of metallic tin with four or five parts of potassium carbonate, a substance is obtained which is liquid, compact, opaque, yellow like wax, and crystalline." In the assays given in the table, the quantity of flux was increased in proportion to the percentage of potash added. As this alone might have had a bad effect on the result, a number of assays were made in which the percentage of potash was the same as in Nos. 64 to 68, the total amount of flux, however, not exceeding 30 grams. They were all very unsatisfactory. Over fifteen minutes were required for the fusion, and there was no regularity in the results. To counteract this, assays were made, to which charcoal had been added to strengthen somewhat the weakened action of the diluted fluxes, placing, however, fluxes free from charcoal in the bottom of the crucibles. The buttons gave higher results, but the irregularity in their weights was the same as before. It

[1] Berthier, Traité des Essais, 1847, Vol. II. p. 459.

[2] *Op. cit.*, Vol. I. p. 445.

would appear, therefore, that the potassium cyanide needs to be practically free from potassium carbonate; 9.09 per cent of the latter showing already a loss of 1.34 per cent in the result obtained.

(9.) The effect of sodium carbonate was tried in the same way. Although this alkali is not common with potassium cyanide, it was thought advisable to test it, as, when potassium cyanide is used in blowpipe experiments, it is generally mixed with an equal weight of sodium carbonate.

The mixtures were not so readily fusible as the corresponding potassium charges, and required fifteen minutes, instead of ten as before. They were, however, just as thin when once melted. When cold, the slags were similar to the potassium slags, only more vitreous and harder. The bluish gray shades of color were missing; the slags were white, but had no lustre whatever; the buttons were, on the whole, the same as above, but showed bead-like excrescences.

TABLE XV.

No. of Assay.	Charge.				Resulting Tin.	
	Ore.	KCy.	Na_2CO_3.			
	Grams.	Grams.	Grams.	Per ct. in mixture.	Grams.	Per cent.
69	5	30	3	9.09	3.315	66.30
70	5	30	6	16.66	3.280	65.60
71	5	30	9	23.07	3.270	65.40
72	5	30	12	28.57	3.110	62.20
73	5	30	15	33.33	3.055	61.10
74	5	30	18	37.50	3.025	60.50
75	5	30	21	41.17	2.910	58.20

Table XV., it will be seen, contains no columns for tin in slags or crucible, and the percentage of tin extracted is smaller than with the potassium salt, the inevitable conclusion being that an admixture of soda has a still more deleterious effect on the result than one of potash.

(10.) The influence of potassium sulphate is a very bad one. Bloxam[1] states that, in the presence of potassium sulphate, stannous

[1] Journal of the Chemical Society, New Series, 1865, Vol. III. p. 97.

and stannic sulphides are formed; the former if the proportion of sulphate be small, the latter if sufficiently large, the stannous sulphide remaining undissolved as a black powder if the slag be treated with water, the stannic sulphide going into solution, and being precipitated as yellow sulphide upon acidulating.

In the experiments, different amounts of potassium sulphate were added to 30 grams of potassium cyanide, and two thirds of the new flux mixed with the ore, one third being placed in the bottom of the naked crucible. The time required for tranquil fusion was ten minutes.

The charges fused readily, and the crucibles were not attacked; the surface of all the slags was smooth, the color deepening with the percentage of potassium sulphate from light red, with a dark rim, to black. The fracture was at first similar to that of pure cyanide, and grew finer until it became stony; the color, at first very light peach-blossom, became darker, till it reached, with the last assay, a dark flesh-color. The hardness and toughness of the slags also increased with the percentage of potassium sulphate.

TABLE XVI.

No. of Assay.	Charge.				Resulting Tin.	
	Ore.	KCy.	K_2SO_4.			
	Grams.	Grams.	Grams.	Per ct. in mixture.	Grams.	Per cent.
76	5	30	0.3	0.99	3.185	63.70
77	5	30	0.6	1.96	No button.	No button.
78	5	30	1.0	3.22	3.060	61.20
79	5	30	2.0	6.25	2.525	50 50
80	5	30	3.0	9.09	2.490	49.80
81	5	30	4.0	11.76	2.435	48.70
82	5	30	5.0	14.28	2.250	45.00

The results obtained show a gradual decrease in the percentage of tin. One per cent of potassium sulphate causes already a loss of 4.14 per cent tin. In assay No. 76 some stannous sulphide was present; it decreased in No. 77, and was absent in No. 78, which, when acidulated, gave a copious precipitate of stannic sulphide. The deleterious influence of potassium sulphate, which was first shown by Bloxam, is thus verified by a series of systematic figures.

TABLE XVII.

No. of Assay.	Granular Purified. Resulting Tin.		No. of Assay.	Pure for Gold Platers. Resulting Tin.		No. of Assay.	Common Fused. Resulting Tin.		No. of Assay.	Common for Mining Purposes. Resulting Tin.	
	Grams.	Per ct.		Grams.	Per ct.		Grams.	Per ct.		Grams.	Per ct.
83	3.225	64.50	86	3.370	67.40	89	3.220	64.40	92	3.115	62.30
84	3.225	64.50	87	3.355	67.10	90	2.990	59.80	93	3.010	60.20
85	3.100	62.00	88	3.340	66.80	91	2.905	58.10	94	2.900	58.00
Aver.	3.183	63.66	Aver.	3.355	67.10	Aver.	3.038	60.76	Aver.	3.008	60.16

(11.) Various grades of the commercial potassium cyanide were obtained and tested. The grade of the cyanide can be judged from its general appearance, the pure being coarsely crystalline, soft, and snow-white. The lowest grade — " or mining purposes " — is reached when the structure becomes stony, and strongly resists pulverization; the color is a decided gray, resulting from finely divided iron.

In each experiment 20 grams of the special brand of cyanide were mixed with 5 grams of ore, 5 grams being reserved for the bottom of the crucible, and 5 grams for a cover. The average time required for tranquil fusion was ten minutes.

a. " Granular Purified," — 86 to 90 per cent KCy, with some KOCy and K_2CO_3, — $1.25 per pound.

The upper slag did not have the beautiful crystalline structure nor the strong lustre of the pure cyanide. It was white, but showed a bluish tinge near the top. The average result is 4.18 per cent too low, and the greatest discrepancy between the single results is 2.50 per cent.

b. " Pure for Gold Platers," — 92 per cent KCy, 5 per cent KOCy, and 3 per cent other salts, — $1.25 per pound.

The general characteristics are the same as those of Nos. 83 to 85, but the results are higher and more uniform.

c. " Common Fused," — 85 per cent KCy, — $0.55 per pound.

The upper slag has a stony fracture, and is of a dull white color. The results are very low and very irregular.

d. " Common for Mining Purposes," — 65 per cent KCy, — $0.50 per pound.

The surface of the slag is smooth, has a dark blue color with gray and yellow streaks passing through it. The fracture is stony, the slag is hard and tough, and is flesh-colored. The results are as bad as those from Nos. 89 to 91.

It will be seen that, of the different grades, only the brand "Pure for Gold Platers" produces results — 0.74 per cent too low — which are sufficiently accurate for every-day purposes. As these brands represent each a certain definite grade of a particular firm, it will be seen that the assayer is obliged to test each separately, making the ordinary chemically pure potassium cyanide — 98 per cent KCy and 2 per cent KOCy — his standard.

THE ENGINEERING LABORATORIES.

BY GAETANO LANZA, PROFESSOR OF APPLIED MECHANICS, IN CHARGE OF THE DEPARTMENT OF MECHANICAL ENGINEERING.

IN the "Technology Quarterly" for May, 1888, an article was published which gave the history of the Engineering Laboratories up to within two years of the present time. Before February 1, 1890, they occupied a little more than one half the basement of the Rogers Building; and inasmuch as that space was already pretty well filled at the time the article was written, it may be said to represent fairly well their condition up to the last mentioned date. The number of students who are now using these laboratories, however, is so large, that it would not be possible to accommodate them all in the Rogers Building. Hence a new Engineering Building has been erected on Trinity Place, not far from the other buildings of the Institute; and it is the object of the present article to describe this building and the present condition of the Engineering Laboratories.

The building covers a ground area of 52 feet by 148 feet, and is six stories high; the two lower floors being entirely devoted to the Engineering Laboratories, while the two middle floors are occupied by the drawing-rooms and recitation-rooms of the Mechanical Engineering Department, and the two upper floors by the drawing-rooms and recitation-rooms of the Civil Engineering Department.

The general style of the building is that of the modern mill, a row of cast-iron columns extending lengthwise through the middle of each floor, at distances of eight feet, centre to centre.

A pair of yellow-pine beams bolted together about one inch apart extends from each column to each lateral wall, the spans being about 24 feet.

The beams supporting the basement floor are each 11 inches by 18 inches; those supporting the first floor, 10 inches by 18 inches; those supporting the second, 7 by 16 inches; and above that, 6 by 16 inches. In the basement the under flooring is 4 inches thick, and on all the other floors 3 inches thick, while the top floors are all ⅞ inch thick.

The wall on the south side is like that of a pilastered mill, while that on the north side is more architectural.

It will thus be seen that the aim has been to construct a building which, while containing heavy machinery in operation, should be sufficiently free from vibration to render it possible to make experiments requiring delicate measurements.

Another engineering feature which ought to be mentioned is that the building does not contain any boilers, but that the steam for heating and also for power is furnished from the boilers in the basement of the Rogers Building, whence it is conveyed through a six-inch pipe about 1,000 feet long, buried under the ground, and protected by being wrapped in two thicknesses of asbestos and inserted in a wood log.

The heating system, which is partly direct and partly indirect, was designed by Mr. S. H. Woodbridge, and the ventilation is obtained by means of a Sturtevant blower acting in connection with the indirect portion of the system.

Automatic valves are used almost entirely on the radiators, so that the steam supply to any radiator is regulated automatically by the temperature of the room.

These laboratories are now called the Engineering Laboratories, and the building is called the Engineering Building, because it is especially devoted to the engineering work of the school, both the general and the special. Thus, in its recitation-rooms are taught the classes in mechanism, in thermo-dynamics and steam engineering, in hydraulics, and in strength of materials, all of which may be called general engineering studies, as all these subjects are taught, to a greater or less extent, to the students of civil, of mechanical, of mining, of chemical, and of electrical engineering. Besides this, all the drawing-room work of the students of these courses is done in this building, and all the purely professional work of the civil and mechanical engineering courses is carried on here; this including practically all the *engineering* work proper of the above stated courses. Hence it follows that it is the building where the purely engineering work is done for all departments of the school.

The Laboratories are really an aggregation of the following: —

1. A laboratory devoted to experimental work upon the strength and other resisting properties of materials used in construction.
2. A laboratory of steam engineering.
3. An hydraulic laboratory.
4. A laboratory where other engineering experiments are made, but which is not yet sufficiently differentiated to be divided into its component parts.

The objects to be accomplished by these laboratories are the following: —

First. To give the students practice in such experimental work as any engineer is constantly liable to be called upon to perform in the practice of his profession; as boiler tests, engine tests, power determinations, etc.

Second. To give the students some experience in carrying on original investigations in engineering subjects with such care and accuracy as to render the results of real value to the engineering community.

Third. By publishing from time to time the results of such investigations, to add gradually to the common stock of knowledge.

The two lower floors of the building are entirely devoted to the Engineering Laboratories, thus increasing their capacity from about 5,550 square feet, as in the Rogers Building, to about 13,900 square feet. Cuts of these laboratories are shown here, and the following statement of the apparatus they contain is copied from the twenty-fifth Catalogue of the Institute: —

"The laboratory for testing the strength of materials is furnished with the following apparatus. An Olsen testing machine of 50,000 pounds' capacity, for determining tensile strength, elasticity, and compressive strength. A testing machine of the same capacity for determining the transverse strength and stiffness of beams up to 25 feet in length, and of framing-joints used in practice. Machinery for the measurement of the strength, twist, and deflection of shafting while running and under the conditions of practice. Machines for time tests of the transverse strength and deflection of full-sized beams; for testing the tensile strength of mortars and cements, and of ropes; for testing the effect of repeated stresses upon the elasticity and strength of iron and steel; for determining the strength and elasticity of wire; for determining the deflection of parallel rods when running under different conditions. Also accessory apparatus for measuring stretch, deflection, and twist.

"The hydraulic laboratory contains, — A closed tank 5 feet in diameter and 27 feet high, connected with a stand-pipe 10 inches in diameter and about 90 feet high. Apparatus, in connection with the tank and stand-pipe, for making experiments on the flow of water through orifices and mouth-pieces, over weirs and in pipes, under different heads and under different conditions, and on the losses of head occurring under different circumstances. A 6-inch Swain turbine, so arranged that it can be run under different heads, and that measurements can be made of the power exerted, of the efficiency, etc., under different gates.

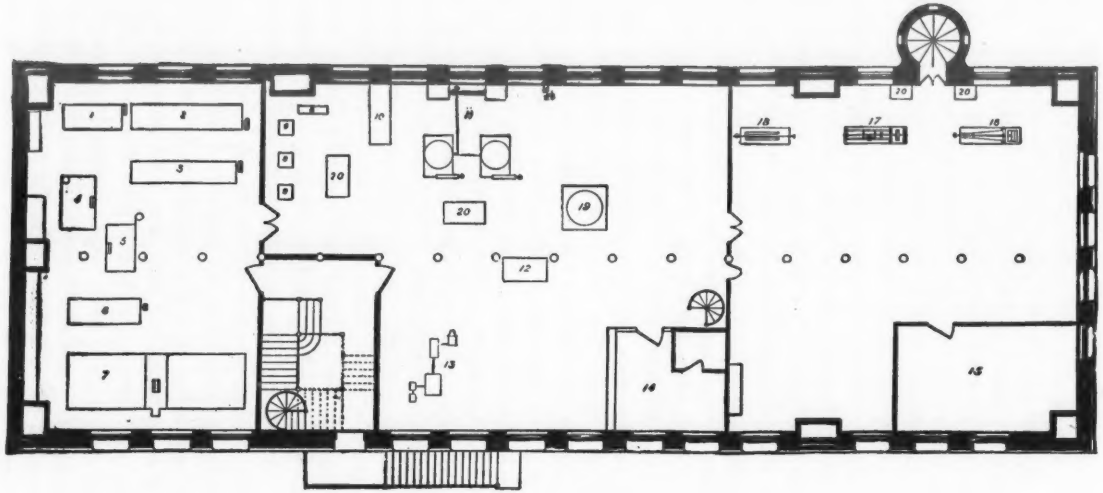
"The steam laboratory contains, — A triple expansion engine, with cylinders of 9 inches', 16 inches', and 24 inches' diameter respectively, and 30 inches' stroke, arranged in such a way as to be run single, compound, or triple, as desired for the purposes of experiment. This engine is of the Corliss type, and was built by E. P. Allis & Co. It will have a capacity of about 150 horse-power when running triple, with an initial pressure of 150 pounds in the high pressure cylinder. It is connected with a surface condenser and all the other apparatus necessary to adapt it to the purposes of accurate experiment.

"This laboratory also contains a 16 horse-power Harris-Corliss engine, and an 8 horse-power engine, used for giving instruction in valve-setting, etc. It is also equipped with several surface condensers, steam pumps, calorimeters, mercurial pressure and vacuum columns; apparatus for determining the quantity of steam issuing from a given orifice or through a short tube under a given difference of pressure; apparatus for testing injectors; and with indicators, planimeters, gages, thermometers, anemometers, and other accessory apparatus.

"The engineering laboratories are also provided with a number of friction brakes; with machinery for determining the tension required in a belt or rope to enable it to carry a given power at a given speed, with no more than a given amount of slip; with three transmission dynamometers; with a complete set of Westinghouse air-brake apparatus, including the parts belonging on the car and on the locomotive; with cotton machinery as follows, namely, two cards, a drawing frame, a speeder, a fly frame, a ring frame, and a mule, as well as accessory apparatus. There are also available for the purposes of experiment, in connection with the work of these laboratories, two horizontal tubular boilers, one large Babcock and Wilcox boiler, and a Porter-Allen engine of about 80 horse-power, all situated in the Rogers Building; also another boiler, a 40 horse-power Brown engine, a number of looms, and other apparatus in the workshops on Garrison Street."

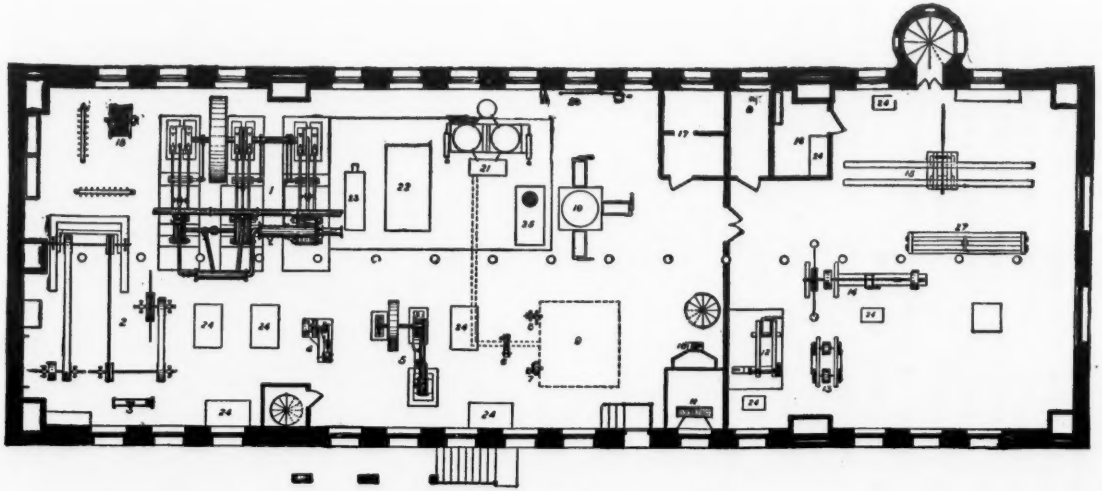
The most important addition to the equipment of these laboratories is that of the triple expansion engine, inasmuch as it is the first triple expansion engine of a practical size that has ever been arranged for making experiments; and by its means the laboratories are placed in a position which will enable them to do work for the triple engine of a character similar to that done for the compound engine by the United States Naval Engineers in 1874, and also to make such researches with a triple or a compound engine as were made upon single engines by Hirn, Hallauer, and others.

The hydraulic tank and stand-pipe places this laboratory in a posi-



FIRST FLOOR.

1. Drawing-Frame.
2. Speeder.
3. Fly-Frame.
4. Carding Engine.
5. Carding Engine.
6. Spinning Frame.
7. Mule.
8. Calorimeters.
9. Calorimeters.
10. Calorimeters.
11. Injector and Weighing Tanks.
12. Tank for Turbine-Wheel.
13. Westinghouse Air Brake.
14. Office.
15. Office.
16. Olsen's Fifty-Thousand Pounds Tension Machine.
17. Repeated-Bending Machine.
18. Cement-Testing Machine.
19. Tank for Hydraulic Experiments.
20. Tables.
26. Mercury Column.



BASEMENT, 150 × 50 FEET.

1. Triple Expansion Engine, 150 H. P.
2. Rope and Belt Transmission Testing Machine.
3. Engine Lathe.
4. Kendall Engine, 8 H. P.
5. Harris-Corliss Engine, 16 H. P.
6. Steam Pump.
7. Rotary Pump.
8. Centrifugal Pump.
9. Tank.
10. Fan Engine.
11. Steam Pipes for Heating Air.
12. Rope-Testing Machine.
13. Parallel-Rod Machine.
14. Shaft-Testing Machine.
15. Fifty Thousand Pounds Beam-Testing Machine.
16. Cement Room.
18. Dynamo, 500 Lights.
19. Wrought-Iron Tank for Hydraulic Experiments (5 feet diameter, 27 feet high).
20. Hydraulic Stand-Pipe (10 in. diam., 85 feet high).
21, 22. Cisterns.
23. Condenser.
24. Tables.
25. Turbine-Wheel and Tank.
26. Mercury Column.
27. Apparatus for Time Test of Wooden Beams.

tion to perform some work of great value in hydraulic experiments which would be impossible without such apparatus. The laboratory with its present equipment furnishes the means, — 1st, of accommodating the number of students that now need this instruction, with an opportunity for some growth; 2d, of giving good laboratory instruction to the students; 3d, of carrying on investigations of importance in the engineering line. All this can be done, inasmuch as the building is adapted to the purposes of an engineering laboratory, — a fact which was never true of the Rogers Building.

The two middle floors are devoted to drawing-rooms and recitation-rooms for the Mechanical Engineering Departments, the drawing-rooms being well arranged to furnish good light. The two upper floors contain, as has been said, the drawing-rooms and recitation-rooms of the Civil Engineering Department, and also the Engineering library, which is common to both departments.

THE VELOCITY OF BODIES OF DIFFERENT SPECIFIC GRAVITY FALLING IN WATER.[1]

BY ROBERT H. RICHARDS, PROFESSOR OF MINING AND METALLURGY, AND A. E. WOODWARD, S. B.

IN Rittinger's "Aufbereitungskunde" of 1867 occurs (p. 195) the following table, which shows the rate of falling in water of fragments of minerals of irregular shapes and of five different specific gravities: —

		Diameter of Particles in Millimeters.							
		10	8	6	4	3	2	1	.5
	Sp. Gr.	Velocity in Meters per Second.							
Auriferous Silver	15.0	.90	.80	.70	.57	.50	.40	.29	.20
Galena	7.5	.62	.55	.48	.39	.34	.28	.20	.14
Pyrites	5.0	.49	.43	.38	.30	.26	.22	.15	.10
Quartz	2.6	.30	.27	.24	.19	.17	.14	.10	.07
Coal	1.3	.13	.12	.10	.08	.07	.06	.04	.03

With the purpose of extending this valuable table to cover a larger number of minerals and sizes of each mineral, and of making it more easy of application in deciding upon a sieve-scale for any group of minerals, we have prepared the curves of velocity of fall of bodies in water shown in Plates I., II., III., and IV., using Rittinger's formula

$$V = 2.44 \sqrt{D(\delta - 1)};$$

where V = velocity in millimeters per second,
" D = diameter of particles in meters,
" δ = specific gravity of the mineral.

These curves embrace a large number of specific gravities, and for each specific gravity the relation of the diameter of the mineral particle to the velocity of its fall in water is given for all diameters and velocities used in practice.

The second diagram is an enlargement of the lower left-hand corner of the first, the third bears the same relation to the second, and in like manner the fourth to the third. Plate I., therefore, covers the work

[1] Presented at a meeting of the American Institute of Mining Engineers, Washington, D. C., February, 1890.

Substance.	Sp Gr. δ.	Substance.	Sp. Gr. δ.
Mineral Coal	1.0 - 1.8	Stibnite	4.5
Gypsum	2.3	Tetrahedrite	4.5 5.1
Chrysocolla	2.0 2.2	Bornite	4.4 5.5
Graphite	2.09	Marcasite	4.68 4.85
Quartz	2.5 2.8	Pyrolusite	4.8
Orthoclase	2.44 2.6	Greenockite	4.8 5.0
Serpentine	2.5 2.65	Pyrite	4.8 5.2
Oligoclase	2.56 2.72	Menaccanite	4.5 5.0
Calcite	2.5 2.78	Hematite	4.5 5.3
Labradorite	2.67 2.76	Millerite	4.6 5.65
Talc	2.57 2.8	Magnetite	4.9 5.2
Pyrophyllite	2.75 2.92	Franklinite	5.07
Muscovite	2.75 3.1	Miargyrite	5.2 5.4
Anhydrite	2.9	Proustite	5.4 5.6
Dolomite	2.8 2.9	Chalcocite	5.5 5.8
Margarite	2.99	Zincite	5.4 5.7
Cryolite	2.9 3.07	Cerargyrite	5.55
Amphibole	2.9 3.4	Pyrargyrite	5.7 5.9
Apatite	2.9 3.25	Cuprite	5.85 6.15
Tourmaline	2.9 3.3	Scheelite	5.9 6.1
Fluorite	3.0 3.25	Cobaltite	6.0 6.3
Forsterite	3.3 3.5	Arsenopyrite	6.0 6.4
Pyroxene	3.2 3.5	Tellurium	6.1 6.3
Epidote	3.25 3.5	Anglesite	6.1 6.4
Fowlerite	3.4	Wulfenite	6.0 7.0
Rhodonite	3.4 3.68	Polybasite	6.2
Rhodochrosite	3.4 3.7	Stephenite	6.27
Azurite	3.5 3.8	Cassiterite	6.4 7.1
Diamond	3.53	Smaltite	6.4 7.2
Calamine	3.16 3.9	Cerussite	6.5
Garnet	3.15 4.3	Pyromorphite	6.5 7.1
Siderite	3.7 3.9	Wolframite	7.1 7.55
Limonite	3.6 4.0	Argentite	7.19 7.36
Malachite	3.7 4.0	Galenite	7.25 7.7
Atacamite	3.8	Niccolite	7.3 7.7
Sphalerite	3.9 4.2	Sylvanite	7.99 8.3
Corundum	3.9 4.2	Copper	8.84
Willemite	3.9 4.18	Cinnabar	9.0
Tephroite	4.0 4.1	Silver	10.1 11.1
Smithsonite	4.0 4.5	Amalgam	10.5 14.0
Chalcopyrite	4.1 4.3	Palladium	11.3 11.8
Chromite	4.3 4.57	Mercury	13.57
Barite	4.3 4.7	Gold	15.6 19.5
Enargite	4.4 4.45	Platinum	16.0 19.0
Pyrrhotite	4.4 4.7	Iridosmine	19.3 21.12
Molybdenite	4.4 4.8	Platiniridium	22.6 23.0

of the coarsest jigging 2 inches in diameter; and Plate II. covers from $\frac{1}{2}$ inch downward; Plate III., from $\frac{1}{10}$ inch downwards; Plate IV., from $\frac{1}{60}$ inch downwards.

We have compiled a table, which appears on the opposite page, of most of the minerals likely to demand water separation, using the specific gravities given in Dana's "System of Mineralogy."

The diagrams may be used in determining, for any group of minerals to be separated, a sieve-scale; that is to say, a list of sieves arranged in series in such manner that the sands treated by them shall be suitably prepared for jigging. Rittinger (p. 224) adopts as the most satis-

	Rittinger's Sieve-scale (p 224).	Rittinger's Fall Velocities (p. 271). Velocity of Fall in Meters per Second.	
	Diameter in millimeters.	Galena, sp. gr. 7 5.	Quartz, sp. gr. 2.6.
Group I.	64.0	1.571	0.780
	45.2	1.322	.671
	32.0	1.112	.551
Group II.	22 6	.922	.457
	16.0	.786	.390
	11.3	.661	.328
	8.0	.556	.276
Group III.	5.6	.463	.230
	4.0	.392	.195
	2.8	.327	.161
	2.0	.278	.137
Group IV.	1.4	.232	.115
	1.0	.195	.097
	0.71	.165	.082
	0.50	.138	.073
Group V.	0.35	.116	.058
	0.25	.098	.048
	0.125	.069	.034

Group VI. comprises fine slimes.

factory sieve-scale a list of sieves beginning with one having 1 mm. hole, and ranging upwards in geometric progression by the factor $1.4142 = \sqrt{2}$, and downwards by the reciprocal $\frac{1}{1.4142}$. He proceeds to show (p. 271) that not all the sieves of this scale are needed for separating two minerals of greatly diverse specific gravity; for instance, quartz and galena. This may be deduced from the foregoing table, constructed from his figures.

The smallest grain of galena in any one group will settle more rapidly than the largest grain of quartz in that group.

The sieve-scale required for quartz and galena, as shown by the above table, is then:

Group.	Mesh in millimeters.	
I.	Through 64.0	on 22.6
II.	" 22.6	" 5.6
III.	" 5.6	" 1.4
IV.	" 1.4	" 0.35
V.	" 0.35	" 0.125
VI.	" 0.125	

It is to facilitate the making of such shortened sieve-scales, adapted to special groups of minerals, that the fall-curve diagrams have been constructed. For instance, if it be desired to construct a sieve-scale for the preparation of sands containing quartz (sp. gr. 2.6) and apatite (sp. gr. 3) for jigging, we start with the proviso that in any given group the smallest grain of apatite must have 1 centimeter per second greater velocity than the largest grain of quartz in that group. Taking 1 centimeter = 0.01 meter diameter as the limiting sieve under the rolls, we can then select by inspection from the diagram (Plate II.) the following sieve-scale.

Class.	Mesh in Meters.		Velocity in Meters per Second.	
	Through.	Upon.	Largest Quartz.	Smallest Apatite.
I.	0.01	0.0084	0.304	0.316
II.	0.0084	0.0070	0.280	0.290
III.	0.0070	0.0060	0.256	0.266
IV.	0.0060	0.0050	0 236	0.245
V.	0.0050	0.0042	0.215	0.225

And so on. A similar sieve-scale for classifying, preparatory to jigging, the grains of any two minerals of different specific gravities can be made from the diagrams, with less trouble, we think, than in any other way.

The velocities given in the curves are all of them final velocities, calculated by Rittinger's formula. In quick jigging the conditions of his formula would not be quite realized, as the particles would not have time to acquire their final velocity. To give some idea to what extent the curves would be in error for quick jigging, we add the following table, taken from Rittinger, (p. 178,) but much enlarged.

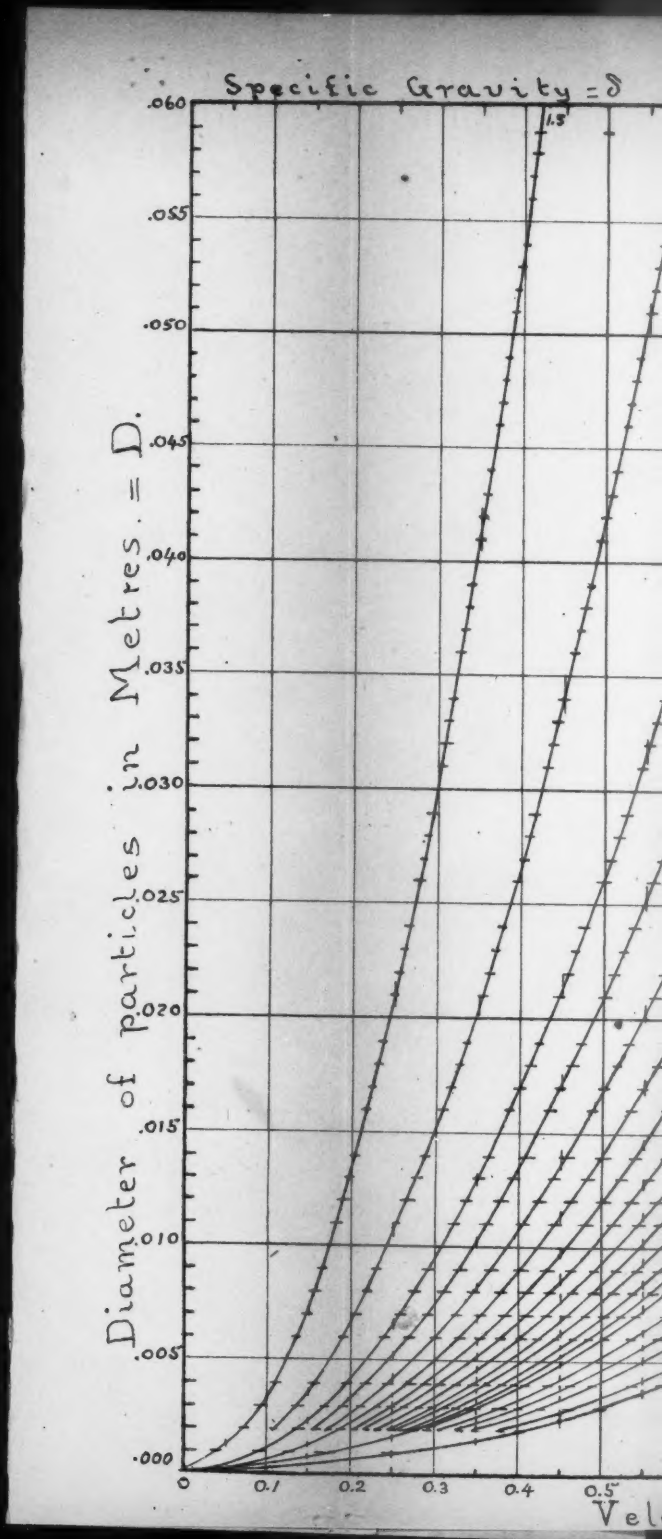
Substance.	Diameter in Meters.	Fall in Meters per Second.					
		$t = 0.062$.	$t = 0.125$.	$t = 0.25$.	$t = 0.50$.	$t = 1.0$.	$t = 2.0$.
PbS	.016	0.514	0.936	*1.416*	*1.630*	*1.650*	*1.650*
FeS_2		0.468	*0.825*	*1.174*	*1.287*	*1.293*	*1.293*
SiO_2		0.353	*0.570*	*0.767*	*0.801*	*0.817*	*0.817*
PbS	.012 ($\frac{1}{2}$ in.)	0.508	0.902	1.290	1.388	1.428	1.428
FeS_2		0.461	0.789	1.054	1.118	1.120	1.120
SiO_2		0.345	0.558	0.689	0.708	0.709	0.709
PbS	.008	0.497	0.842	1.107	1.164	1.166	1.166
FeS_2		0.448	0.723	0.890	0.914	0.915	0.915
SiO_2		0.332	0.499	0.572	0.578	0.579	0.579
PbS	.006 ($\frac{1}{4}$ in.)	0.487	0.790	0.980	1.009	1.010	1.010
FeS_2		0.436	0.669	0.778	0.792	0.792	0.792
SiO_2		0.319	0.454	0.498	0.501	0.501	0.501
PbS	.004 ($\frac{1}{6}$ in.)	0.468	*0.704*	*0.814*	*0.823*	*0.824*	*0.824*
FeS_2		0.414	*0.586*	*0.643*	*0.646*	*0.646*	*0.646*
SiO_2		0.297	*0.383*	*0.409*	*0.409*	*0.409*	*0.409*
PbS	.003 ($\frac{1}{8}$ in.)	0.451	0.645	0.710	0.714	0.714	0.714
FeS_2		0.394	0.527	0.559	0.560	0.560	0.560
SiO_2		0.282	0.344	0.354	0.354	0.354	0.354
PbS	.002 ($\frac{1}{12}$ in.)	0.421	0.553	0.582	0.583	0.583	0.583
FeS_2		0.362	0.445	0.457	0.457	0.457	0.457
SiO_2		0.250	0.286	0.289	0.289	0.289	0.289
PbS	.001 ($\frac{1}{25}$ in.)	0.354	*0.409*	*0.413*	*0.414*	*0.414*	*0.414*
FeS_2		0.294	*0.321*	*0.323*	*0.323*	*0.323*	*0.323*
SiO_2		0.195	*0.203*	*0.204*	*0.204*	*0.204*	*0.204*
PbS	.0005 ($\frac{1}{50}$ in.)	0.277	0.291	0.292	0.292	0.292	0.292
FeS_2		0.222	0.229	0.229	0.229	0.229	0.229
SiO_2		0.143	0.145	0.145	0.145	0.145	0.145

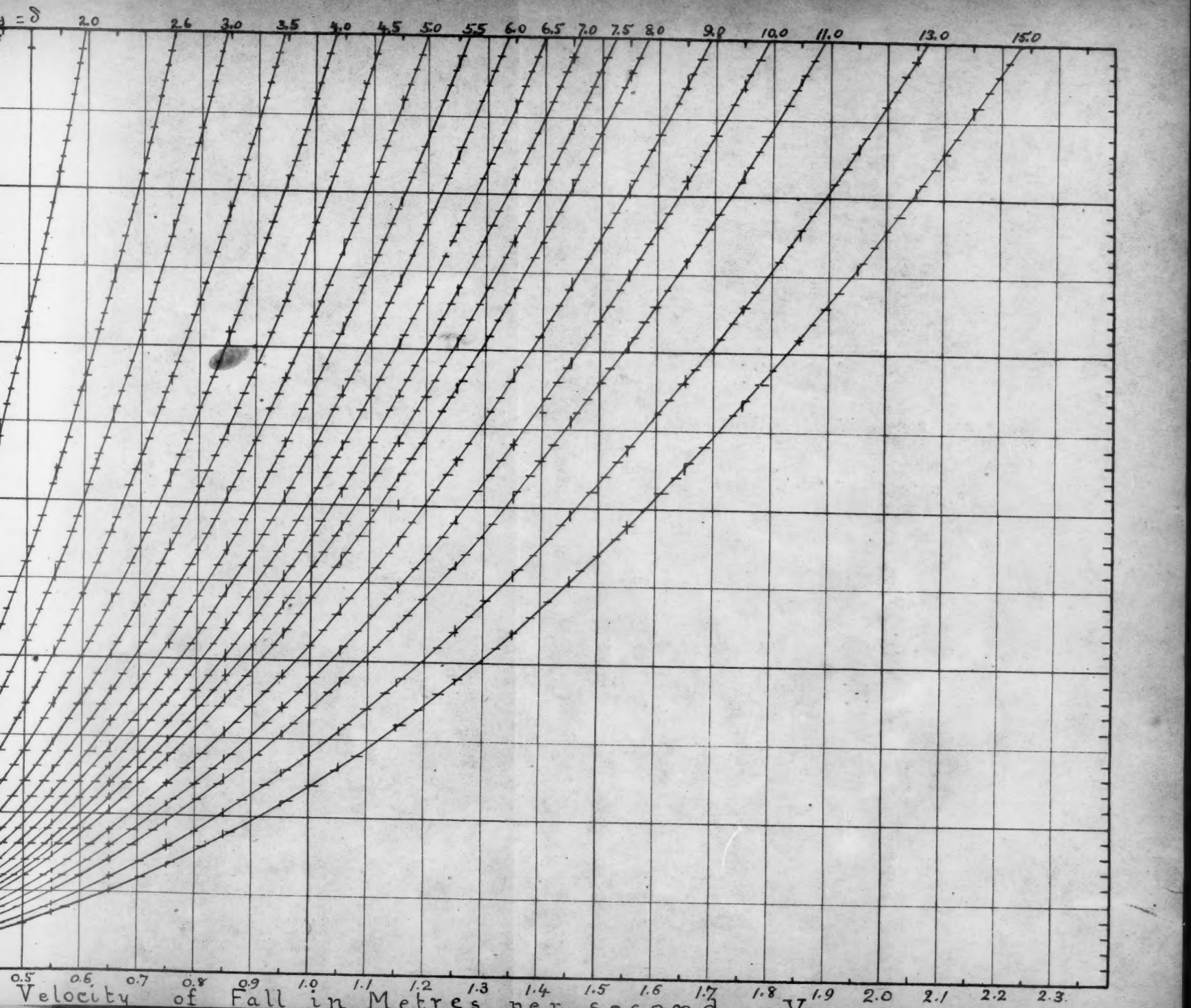
The Italic figures were taken from Rittinger, the others were calculated.

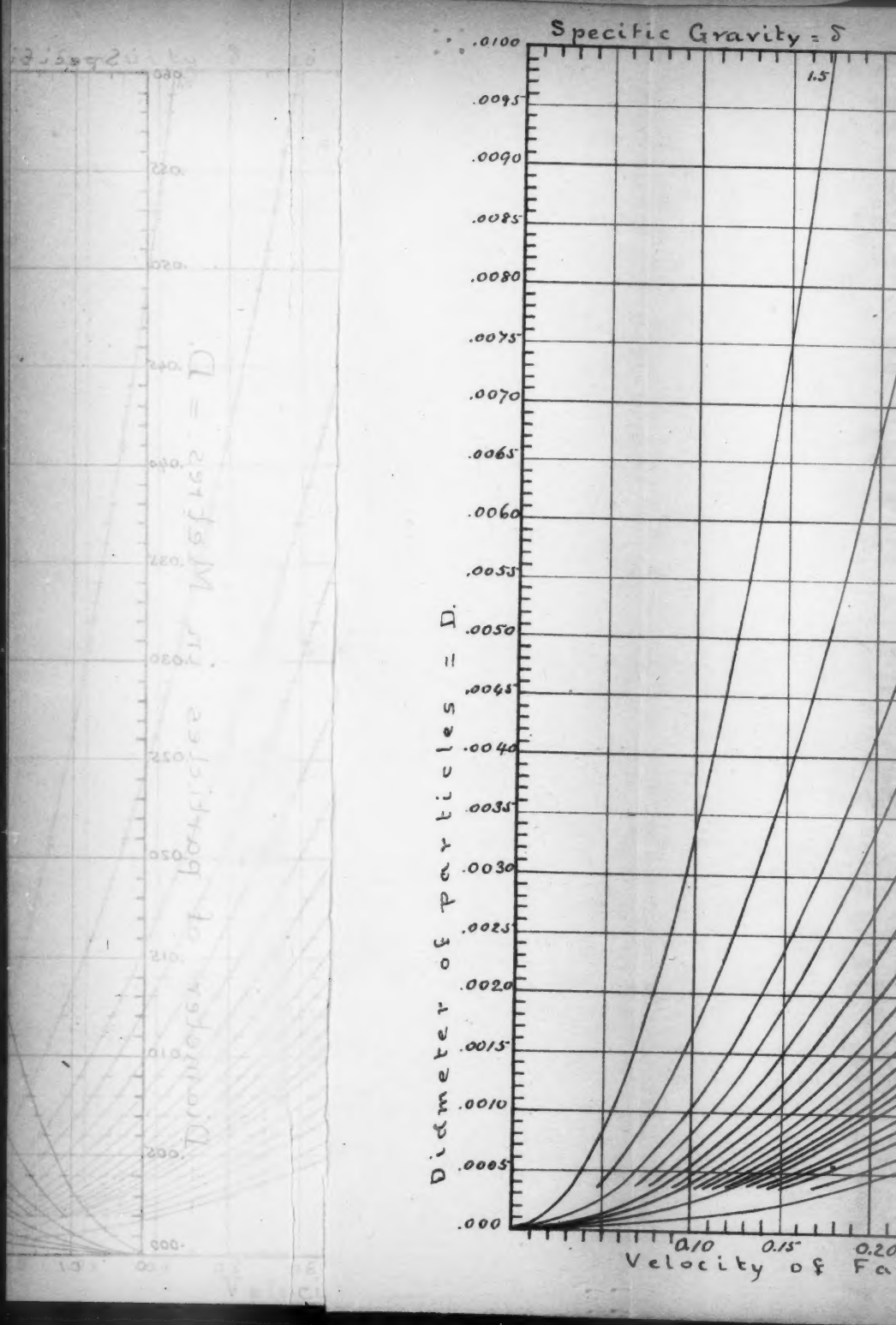
$$V = \frac{1}{A} \times \frac{e^{2Bt} - 1}{e^{2Bt} + 1} \text{ when } B = \frac{g(s-\Delta)}{s} A, \text{ and } A = \sqrt{\frac{3 a_3 \Delta}{2 dj (s-\Delta)}}.$$

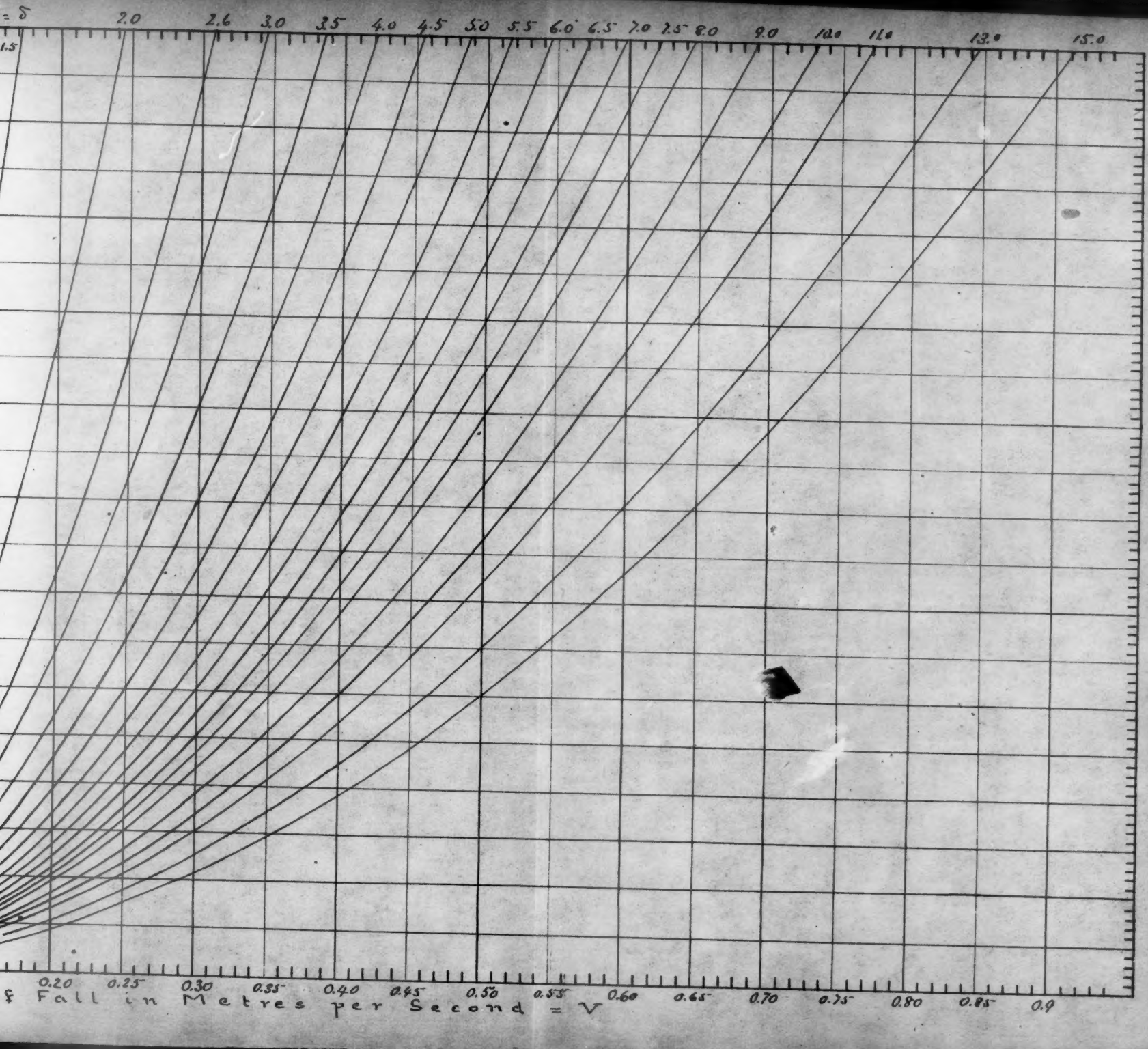
v = velocity of fall in meters per second.
e = Napierian base.
g = acceleration due to gravity.
s = sp. gr. of solid.
Δ = sp. gr. of liquid.
d = diameter of solid.
j = weight of cu. in. of water.
a_3 = constant velocity v after t in seconds.

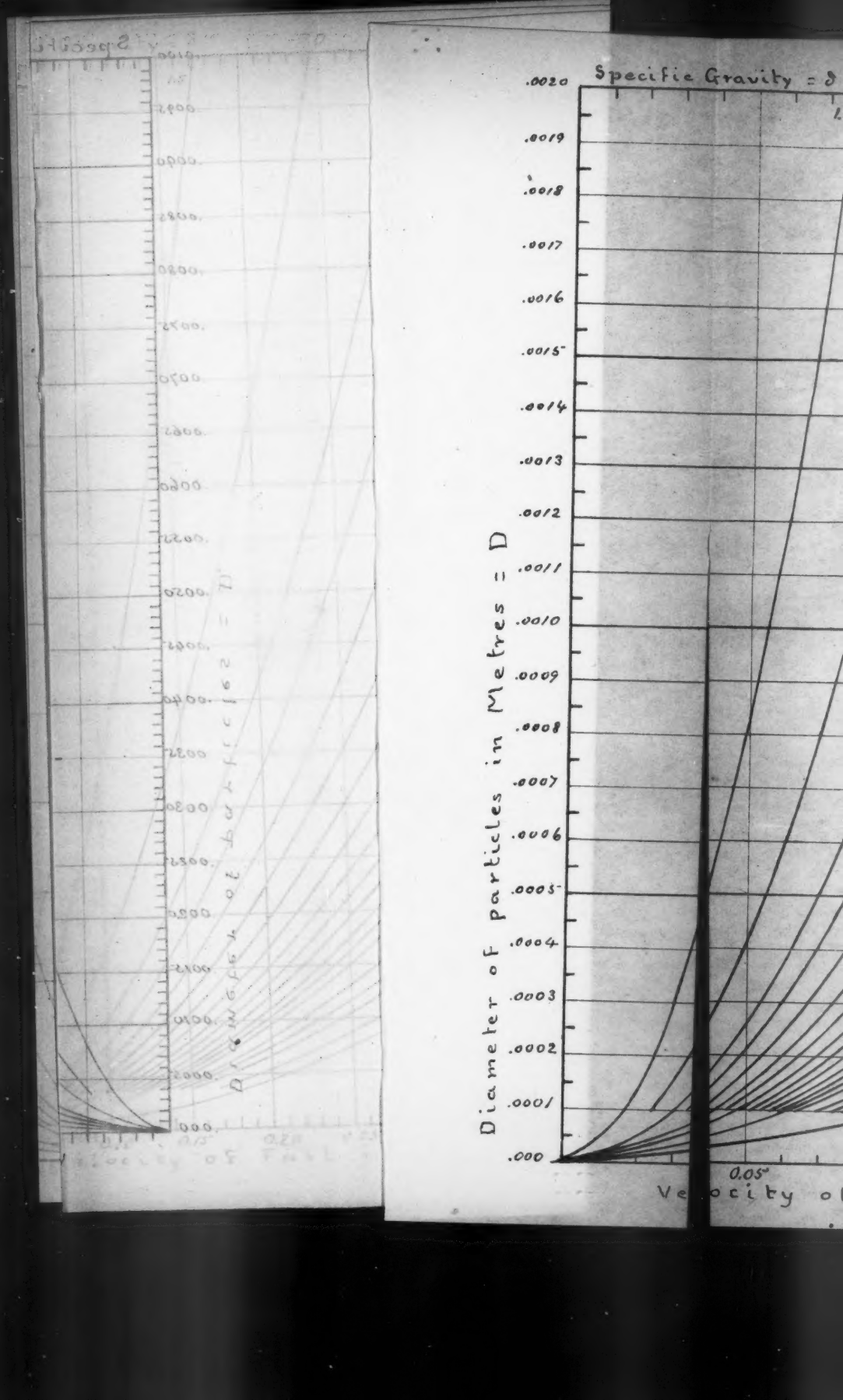
All jigging will practically take place between $t = .25$, or 240 strokes per minute, and $t = .50$, or 120 strokes per minute. Now if we follow down these two columns in the above table, we shall see that this error is serious for 240 strokes with $\frac{2}{3}$ inch, $\frac{1}{2}$ inch, and $\frac{1}{3}$ inch diameter; becomes insignificant with $\frac{1}{4}$ inch, $\frac{1}{6}$ inch, and $\frac{1}{8}$ inch, and disappears practically in $\frac{1}{12}$ inch, $\frac{1}{25}$ inch, and $\frac{1}{50}$ inch diameter; that for 120 strokes per minute it is nowhere serious; is insignificant for $\frac{2}{3}$ inch, $\frac{1}{2}$ inch, and $\frac{1}{3}$ inch diameter, and practically disappears for $\frac{1}{4}$ inch and all below.

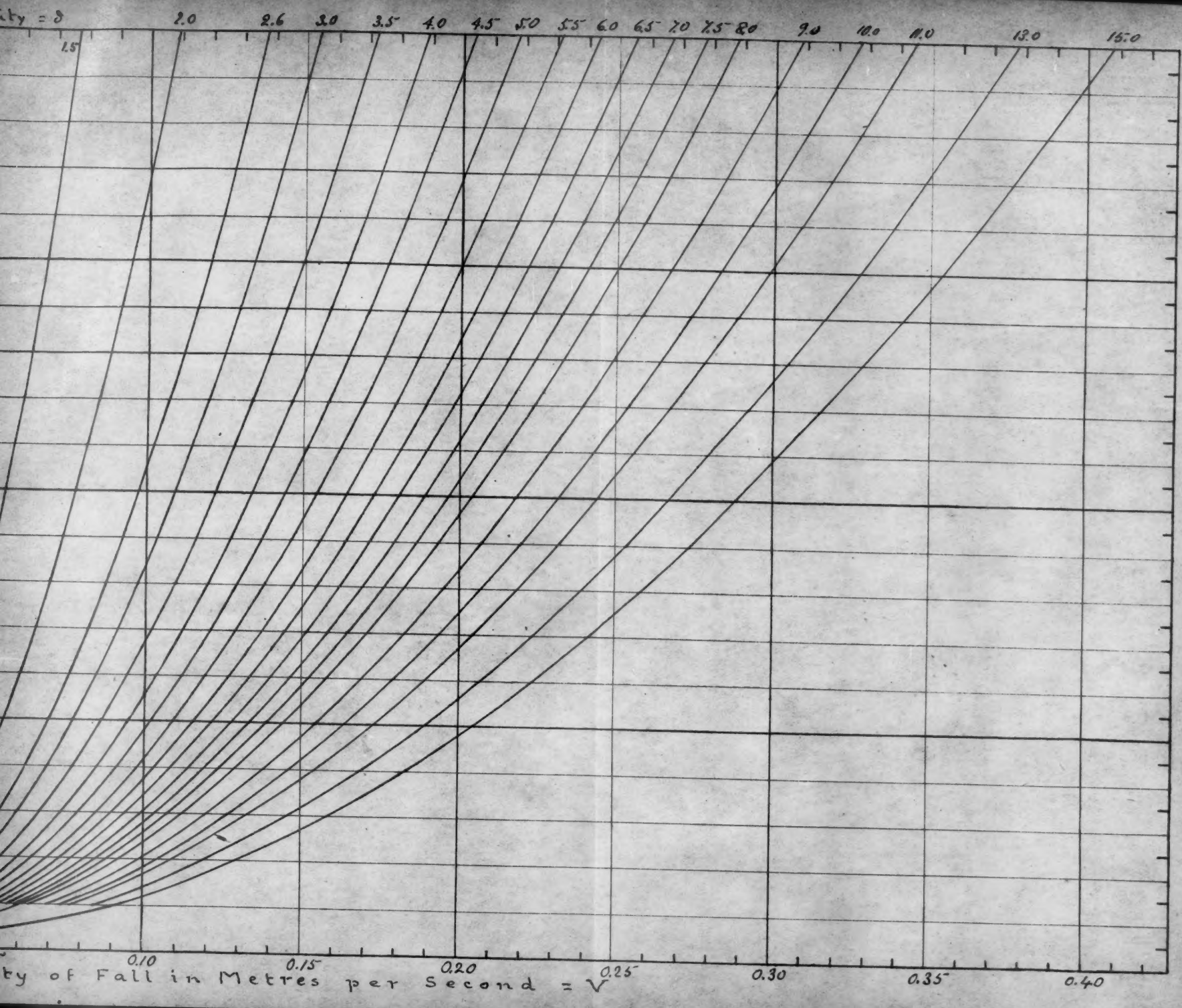

Specific Gravity = S
Diameter of particles in Metres = D.
.060
.055
.050
.045
.040
.035
.030
.025
.020
.015
.010
.005
.000
1.5
0
0.1
0.2
0.3
0.4
0.5
Vel

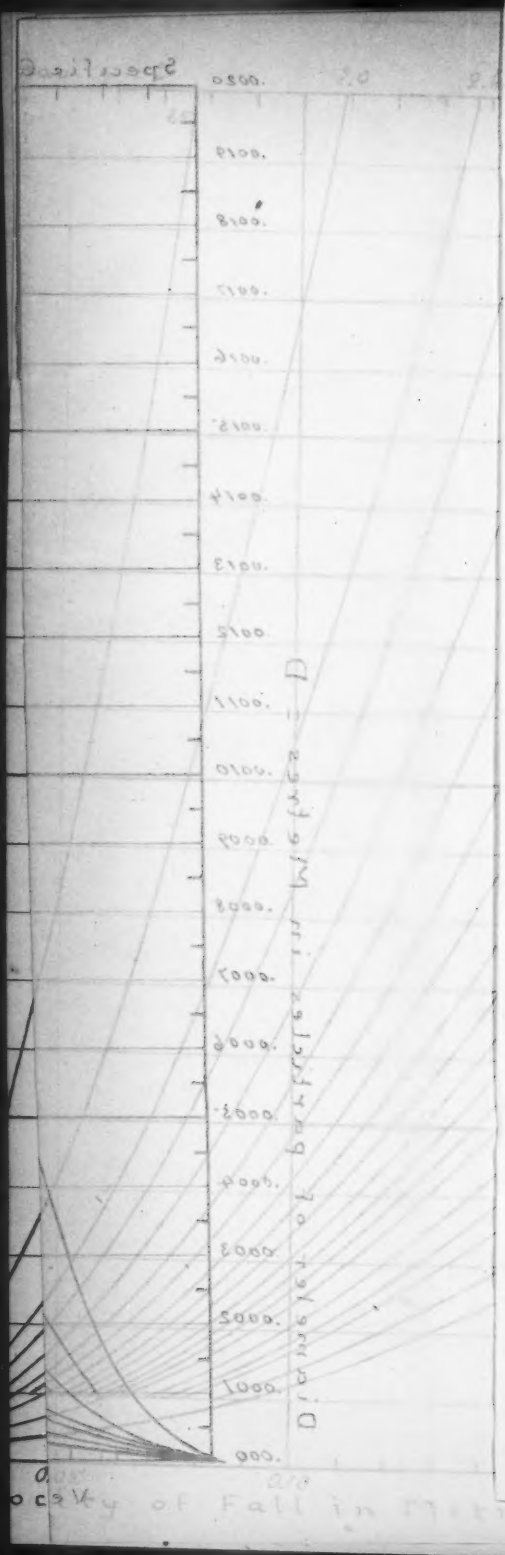

= δ
2.0
2.6
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
9.0
10.0
11.0
13.0
15.0
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
Velocity of Fall in Metres per second. = V

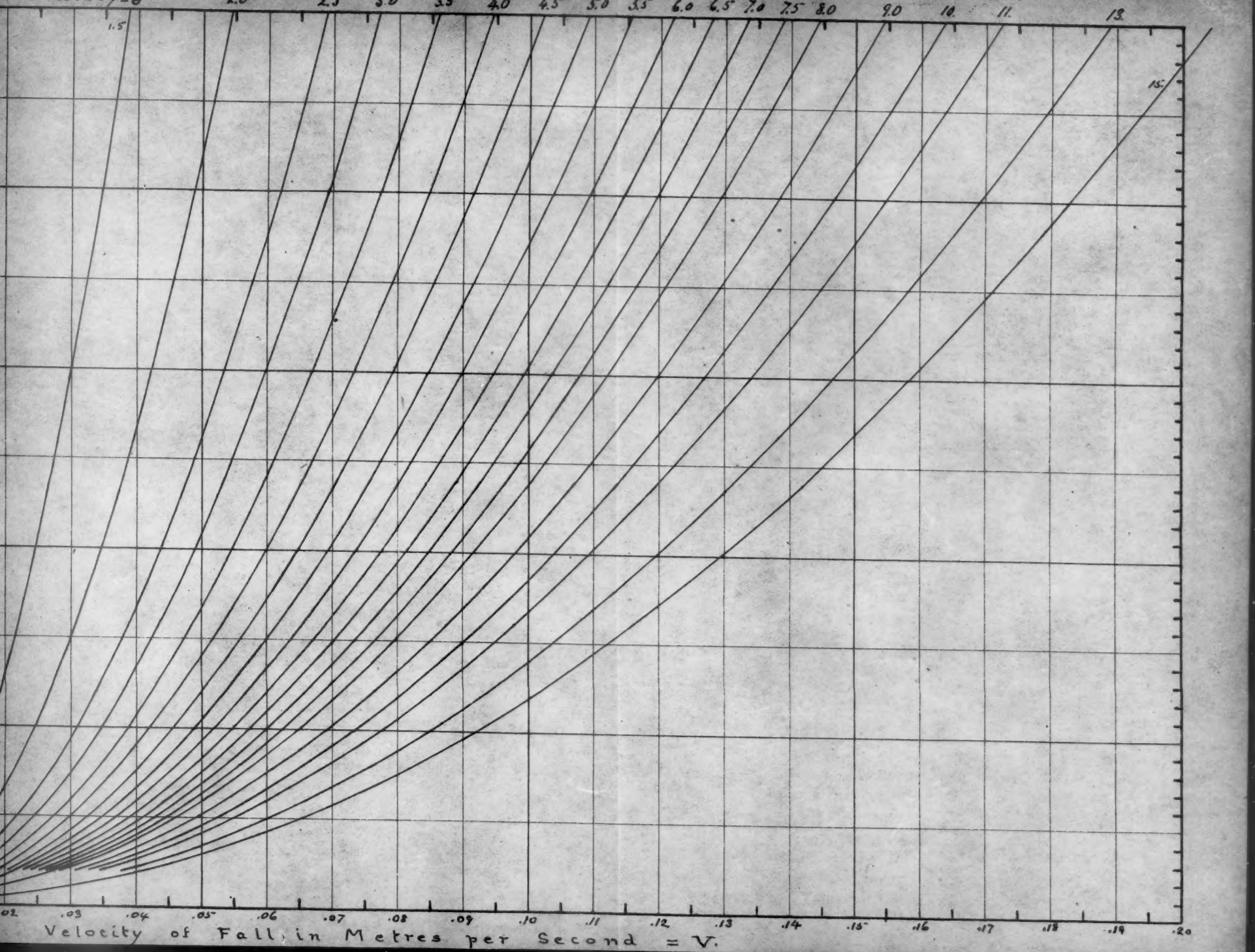

Specific Gravity = δ
1.5
Diameter of particles = D.
.0100
.0095
.0090
.0085
.0080
.0075
.0070
.0065
.0060
.0055
.0050
.0045
.0040
.0035
.0030
.0025
.0020
.0015
.0010
.0005
.000
0.10
0.15
0.20
Velocity of Fa

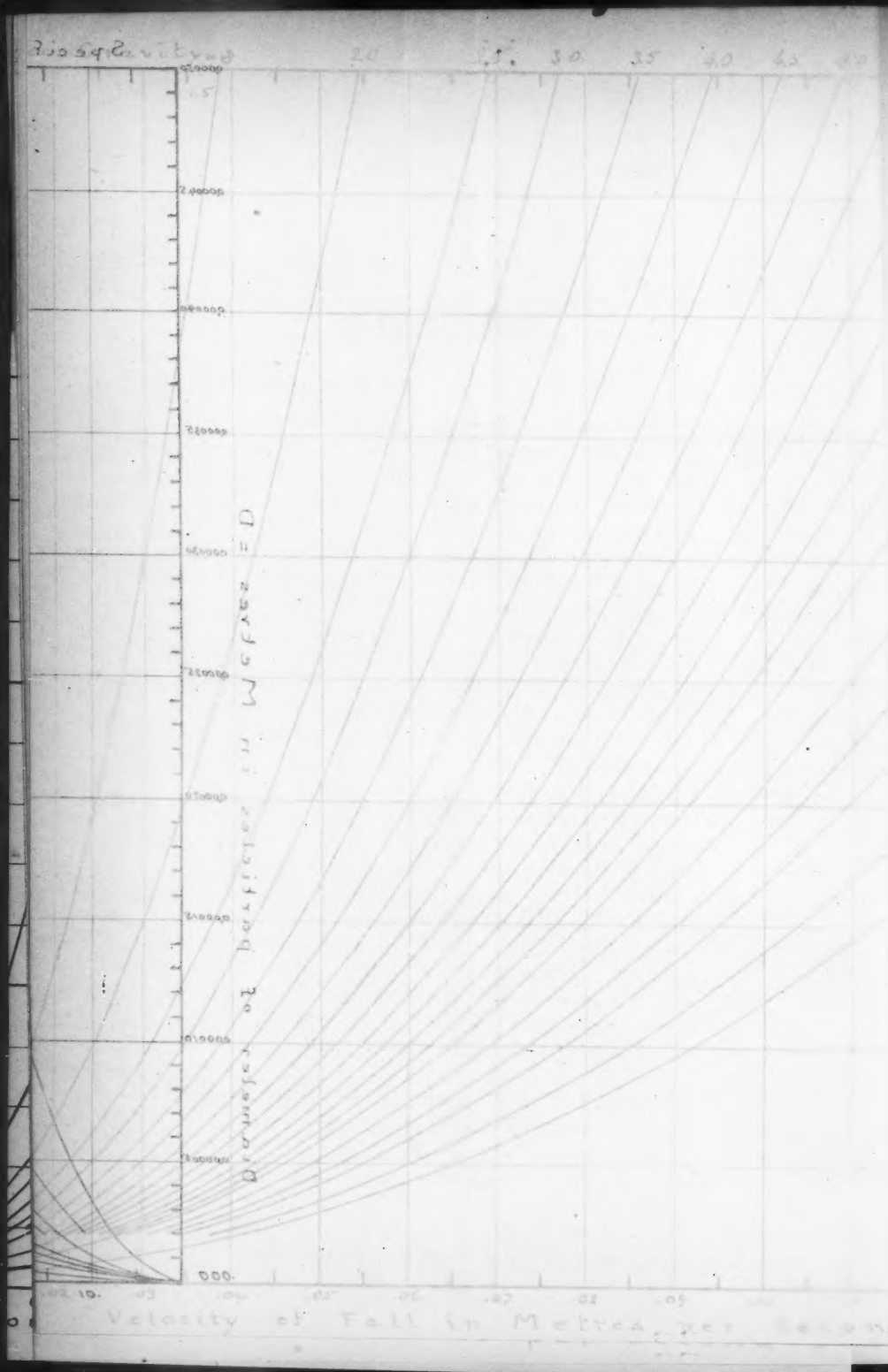

= δ
1.5
2.0
2.6
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
9.0
10.0
11.0
13.0
15.0
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.9
f Fall in Metres per Second = V


Specific Gravity = δ
.0020
.0019
.0018
.0017
.0016
.0015
.0014
.0013
.0012
.0011
.0010
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
.000
Diameter of particles in Metres = D
0.05"


ity = d
1.5
2.0
2.6
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
9.0
10.0
11.0
13.0
15.0
0.10
0.15
0.20
0.25
0.30
0.35
0.40
ty of Fall in Metres per Second = V


Specific Gra
Diameter of particles in Metres = D
.000
.01
.02


e Gravity=s
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
9.0
10.
11.
13.
15.
02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
.15
.16
.17
.18
.19
.20
Velocity of Fall, in Metres per Second = V.


Diameter of Particles in Millimetres
Velocity of Fall in Metres per Second

AN ATTEMPT TO REDUCE ARCHITECTURAL DESIGNING TO A LOGICAL BASIS.

BY C. HOWARD WALKER, INSTRUCTOR IN DESIGN.

THE relation of architecture to the exact sciences is far from being clearly defined. Combining as it necessarily does the elements of a science with those of an art, it has been looked upon askance, on the one hand as indefinite in its methods, on the other as occasionally too mechanical in its results.

As far as construction is concerned, graphical statics and formulæ supply all needs with sufficient exactness; for architecural construction seldom reaches the inspirational stage, and when such an event occurs the assistance of an engineer is usually solicited.

But construction is not, apart from its necessary adequacy, the most important part of architecture, which is to be regarded for its æsthetic qualities. The objection can justly be made, that it is assumed that the inspiration of genius and the vague, intangible æsthetic sense disarm all criticism. Æsthetic, curiously enough, however, is defined as "pertaining to the science of beauty," and science means certain knowledge; therefore it would seem that the principal thing desired in architectural study should be the certain knowledge of beauty.

The completeness of this knowledge is frequently questioned, and it is presumed that there is no fixed standard and no fixed set of laws by which beauty can be determined or gauged; a freedom from bondage, an erratic liberty of expression, being its prerogative by a sort of divine right, and essential to many of its forms. Yet upon observation there seems to be a very close relation between beauty and utility, between the pleasing thing and the necessary thing, and whatever is given to one at the expense of the other appears to injure both.

It is a perfectly easy matter to attempt to beautify at the expense of constructive expression, and just along this line lie most of the errors of æsthetic taste; but it is a very difficult matter to construct well at the expense of artistic expression, since the influence of the force of gravity alone requires an organic method, and a set of forms, masses, and lines, which will be found more pleasurable to the eye in proportion as they more nearly perform their exact duty.

Whether this is from hereditary perception of instability, or from the tendency of like to attract like, — man, a highly developed organism, being appealed to most strongly by the organic quality in his environment, — is a subject for mental philosophy; that the fact exists is undeniable.

It follows, then, that there are two methods of making a building ugly; first, by lack of development of its organic qualities, that is, by crude and inefficient expression of its constructive requirements, and, secondly, by the addition of non-essential forms, so-called artistic accessories, contrary to those requirements.

Conversely, there are two methods of making a building beautiful; by the fullest and most subtle development of constructive requirements, and by the application of forms which accentuate the organic qualities of the work.

Taking this for granted, — and, certainly, but slight objection can be made to the general statement, — the basis of all design must necessarily be a thorough sense of constructive requirements in order to possess the knowledge of the proper points to accentuate; and this should be, not a perception of a number of petty details, of minor threatening weaknesses, but a pervading sense of the great law governing all building, the law of gravitation.

The first necessity, then, is stability; which means that all main lines, except those of metal, must be horizontal or perpendicular, and that the bottom must not be incapable of supporting the top. This latter necessity has a marked influence upon the disposition and the size of openings, and creates the general rule that voids are preferably placed over voids and solids over solids.

The position of the centre of gravity, real or apparent, creates the desire for more solids in proportion to openings at the lower part of the building than at the upper, and the consequent increase in number of openings in the upper part; and the same desire makes the two sides of a building of the same general density, preventing the weighting of one side more than the other.

This wish for apparent balance is the reason for symmetry, which is, practically, corresponding density on either side of a central axis, and which occasions, to a great degree, the planning of buildings on axes, and the subsequent balancing of the masses of the façade. As far as construction is concerned, this need of lateral balance is imaginary; but it is the first and only important departure of the æsthetic requirement from the constructive one, and has as its basis the feeling that all masses are most stable when equally distributed upon a horizontal plane.

Theoretically, this is true, so that the artistic sense, in this case at least, seems to require more rigid adherence to the theoretical law of solids than does the constructive necessity; a rather suggestive fact to those who claim that art is irrational in its methods.

The wall, and columns carrying a lintel or a wall, are the simplest of constructive units, and are the antecedants of all early architectural forms until the arch makes its appearance.

To the wall, as it is built in horizontal courses, is applied the horizontal scheme of lines; to the column and its associate, the pier, the perpendicular scheme. In each the æsthetic method accents the constructional precedent; in one, by the use of accented jointings and by moulded string-courses, cornices, etc.; in the other, by flutings and panels.

The horizontal lines carried through a façade are influenced in their relation to one another in size and distance apart by two desires: first, to make the lower part of a building seem stronger than the upper; secondly, to divide organic portions of the building one from another.

The first influence is felt in the grading of horizontal joints, so that the larger and wider stones are below, and the interval between the joints decreases toward the top, and, as in the use of more numerous openings as the wall ascends, there is produced a graded tone, a tone of comparative strength, expressed by a gradual shading toward the top of the building. The same result is obtained frequently by changing the texture of the stone, as, for instance, when rock or split-face is used in the first story, and cut ashlar above. The American custom of having the first story of buildings of a different and stronger material than is the rest of the façade is a logical result of the same reasoning.

The same diminution of tone appears in the scale of mouldings as they ascend in position. There is, however, a prevalent idea, caused by the fusing of forms by distance, that all ornament near the eye should be smaller than that far from it; but while this may be perfectly true of the finish of detail, the breadth of treatment and interval of repeat and of decorative scheme should be greater at the base of a building than at its top.

The second desire affects the importance of the base, belt, and cornice mouldings.

It is usual, and has become an unchallenged custom, to consider a strong base and a strong cornice as essential features in an architectural design, and constructional derivations are constantly stated

for both; but there seems to be little understanding of the æsthetic reason for the disposition and relative size of bands of mouldings. This reason is, that each organic portion of a building should be defined at its boundaries, and these bands or belts are treated as so many borders confining parts of the building, and separating each part from its neighbor.

The scale of these borders depends upon the quantity of space confined within their parallel lines, and upon the importance of the change from one portion of the building to another; for instance, the base course and the cornice confine between them the entire mass of the façade, and are made, relatively, the strongest borders.

The lower belt courses are apt to confine higher masses of wall than the upper, and are consequently larger.

The entablature has its divisions of epistyle, frieze, and cornice, defined by much smaller borders, as those divisions are secondary and of minor importance.

When portions of the same plane are divided to express organic parts, such as the different stories, etc., the belts have comparatively little width or projection; but when change of plane, or change of form of the solid occurs, the mouldings and decoration become at once more important and more insistent in emphasizing the change. For instance, the cap is inserted where the cylinder of the column changes to the plane surface of the epistyle, and the richness of bed-moulding and soffit where the plane of the cornice breaks forward from the plane of the frieze. This is true of all changes from one geometric solid to another, whether in Classic, Gothic, or Mohammedan architecture,—the more fundamental the change, the firmer and richer become the division lines of moulding defining the point of demarcation.

With the advent of the arch appears a new series of subjects for consideration, first of which is the fact that all arch lines must maintain their integrity throughout, and must be unworried by other lines impinging upon them. Secondly, the arch must be sufficiently weighted both at crown and at haunches, the æsthetic desire here, as is frequently found elsewhere, warning of constructive danger before it becomes actual.

The introduction of the curves of arches also brings up the question of the similarity of quality in detail on a façade; that is, that there should be an equality of strength expressed throughout, and not in one place a low flat arch with great thrust and little resistance, and in another a tall pointed arch with wedge-like obstinacy.

If such change of quantity of force were to be made, it should be

disposed in such a way as to insure an equilibrium of forces; the whole façade should seem to be in equipoise, not with one portion weaker than another.

The same is to be said of the relative scale of detail, whether it is in openings, mouldings, or curving.

Wherever the planes of a solid change at a more obtuse angle than 135°, the change needs to be defined by mouldings, etc.

Wherever geometric solids terminate in a point, it should be accented by some sort of finial; in fact, an exaggeration of visually uncertain constructive facts is one of the chief motives of architectural detail. This is demonstrated by the use of vaulting ribs, rosettes at intersections, triglyphs, gutters, crockets, finials, etc.

There is an axiom in attacking architectural design from a logical standpoint, that wherever quantity of material and consequent inertia is sacrificed, it is made up in vigor of constructive expression.

When the sturdy quality of the Doric is supplanted by the lighter and more graceful Ionic, the flutes of the column become deeper, the horizontal lines of the entablature draw closer together and become more frequent. When the vigorous columns of the Romanesque are multiplied, clustered, it is because the openings in the wall are becoming larger; and, at length, when the Gothic becomes an organism of masses in equilibrium, each pier, column, rib, and arch has its purpose written upon it by insistent lines drawn in the direction of its resisting force.

But the inertia of horizontal masses is injured by being shot through with the nervous vigor of perpendicular supports, and the energy of ascending columns and piers is dulled by the heavy long lines of inert masses. Architecture is not a stuff with warp and woof; it needs a dominant motive, for otherwise the æsthetic sense suspects instability. To it exact equilibrium is uncertain equilibrium, and it prefers the certainty of dominant horizontal or perpendicular lines to the plaid of conflicting forces. Above all, a building is an organism of which each part should perform its function, not only actually but manifestly, and architectural design should be devoted to denoting unmistakably how each function is performed.

Disguise is affectation. Frank exposition of construction is alone commendable, giving logical quality to design; and it is soon apparent that the æsthetic desire, once recognizing this fact, will suggest the most satisfactory construction, while at the same time it satisfies itself.

BIOPHENE.

BY LOUIS E. LEVI, PH. D.

THE gap which now separates the fat from the aromatic series is being rapidly filled. The great researches upon pyridine, pyrrol, furfurane, thiophene, and other groups of bodies similarly derived from the fat series, have already shown to chemists that the words "fat" and "aromatic" must soon be changed to some more appropriate terms. All the reactions which the above groups possess, although they are derived from bodies in the fat series, show them to be closely related to the aromatic compounds.

The actions of acids, halogens, and all other reagents, upon these groups, are more marked, and progress more easily and rapidly, than upon the aromatic compounds. The thiophene discovered by Victor Meyer, being the first body containing sulphur and possessing the properties of aromatic bodies, is of especial interest. During the time the writer had the pleasure of working under Victor Meyer, and later of working with him, the idea of a body similar to benzol, in which two "CH" groups are replaced by two sulphur atoms, was first suggested. The interest in the question, whether a body with the symbol

would also possess the properties of an aromatic compound, was very great. Since the action of phosphorus trisulphide upon succinic acid, $COOH–CH_2–CH_2–COOH$, forms thiophene,

so thiodiglycollic acid, $COOH–CH_2–S–CH_2–COOH$, should, under the same conditions, produce the body which we will call "biophene": —

The probability of the formation of biophene by this reaction is increased by the fact, that while succinic acid and phosphorus trisulphide yield thiophene, thiodiglycollic acid is composed of two half-molecules of succinic acid joined together by an atom of sulphur. Biophene is produced, as was expected, by the above reaction, but only under certain conditions.

The method of distilling the acid with the phosphorus trisulphide, the way in which thiophene is made, yields an impure product containing very little biophene, but yet sufficient to show the characteristic indophenin reaction. In order to obtain biophene in sufficient quantity and purity, the method of its preparation was modified.

Preparation of Biophene.

Five grams of thiodiglycollic acid are mixed with ten grams of phosphorus trisulphide, and placed in a tube, closed at one end, with fifteen to twenty cubic centimeters of ether. The tube is then closed with a fine capillary, placed in an oven, heated two hours at a temperature of one hundred and seventy degrees centigrade. After cooling, the capillary is opened to allow the escape of the hydrogen sulphide formed. The contents of the tube, which has an odor not unlike the secretions of a skunk, is placed in a separating funnel, and washed with potassium hydrate. The alkali is then drawn off, and the remaining oil dissolved in ether and dried with chloride of calcium. After drying thoroughly, the ether is evaporated and the substance fractionated. The oil passes over in fractions between 140° and 170° C., accompanied by a slight decomposition. By refractionating, an oil having the constant boiling point 165°–170° is obtained. This product, when mixed with sulphuric acid and a crystal of isatine added, gives a beautiful violet color, the characteristic indophenin reaction of the thiophenes. The analysis showed that this oil was biophene.

0.180 gr. of the oil oxidized with HNO_3 yielded 0.7208 gr. $BaSO_4$.

	Found	Theory for $C_4H_4S_2$.
Sulphur	55.00	55.17

Aceto-bienone, $C_4H_3S_2COCH_3$.

To a mixture of one gram of biophene, ten grams of petroleum ether, and one gram of acetyl chloride, aluminium chloride is slowly added. A reaction begins immediately, accompanied by the evolution of hydrochloric acid gas. If the flask is shaken every five minutes, the reaction will be quickly finished, and the aluminium compound of the ketone will settle to the bottom of the flask. When on further addition of aluminium chloride no more hydrochloric acid gas is given off, the product is warmed about fifteen minutes upon the water bath, and the petroleum ether poured off. The thick oily mass is then decomposed with ice and water, and purified by distilling with steam. The distillate is extracted with ether, and dried over chloride of calcium. On evaporating the ether, there remains a heavy, slightly colored oil, whose odor is very aromatic and like that of aceto-thienone.

Aceto-bienone distils at a temperature above 300° C., at the same time decomposing. The action of light upon it turns it dark brown. In order to characterize aceto-bienone as a ketone, the phenylhydrazine compound was made.

Aceto-bienone and Phenylhydrazine.

Molecular weights of aceto-bienone, phenylhydrazine, and anhydrous sodium acetate are heated upon the water bath, with a little water, about six hours. On cooling, beautiful red-colored needles precipitate, which upon recrystallizing out of alcohol are obtained pure. The phenylhydrazide has a melting point of 128°, and is soluble in alcohol and ether.

0.156 gr. of the salt oxidized with HNO_3 yielded 0.2905 $BaSO_4$.

	Found.	Theory for $C_4H_3S_2C\overset{CH_3}{\diagdown\!\!\diagup}N_2HC_6H_5$.
Sulphur	25.6	25.8

Oxidation of Aceto-bienone.

To one gram of aceto-bienone take 2.55 gr. $KMnO_4$, and add fifteen cubic centimeters of a 14% KOH solution for every 50 c. c. of a 2% $KMnO_4$ solution. This mixture is placed in a flask with a return cooler attached, and agitated continually. The reaction begins immediately, and the liquid assumes a dark green color. As soon as the green color disappears, the substance is heated on the water bath for thirty minutes, when the oxide of manganese which is formed will settle to the

bottom, leaving a clear liquid. The oxide of manganese is removed by filtration, and the liquid acidified with sulphuric acid and extracted with ether. After the ether solution is evaporated an oil remains, which, on standing, crystallizes. The crystals are purified by crystallization from alcohol or water. The water solution shows the characteristic acid tests with litmus paper and sodium carbonate. The yield being small, an analysis could not be made.

PHENYLBIENYLKETONE, $\begin{matrix} C_6H_5 \\ C_4H_3S_2 \end{matrix}\!\!\rangle CO$,

is formed by the action of benzoyl chloride upon biophene in the presence of aluminium chloride in the same way as the above described aceto-bienone. Phenylbienylketone is a dark brown oil, having a boiling point of 241° C., and is soluble in alcohol and ether.

0.2933 gr. oil yielded 0.6310 gr. $BaSO_4$.

	Found	Theory for $\begin{matrix} C_6H_5 \\ C_4H_3S_2 \end{matrix}\!\!\rangle CO$.
Sulphur	29.18	29.09

NITROPHENYLBIENYLKETONE.

Two grams of phenylbienylketone are slowly mixed, drop by drop, with nitric acid (sp. gr. 1.62), cooled by a freezing mixture of Glauber's salt and hydrochloric acid. As soon as the two substances come in contact, a violent reaction takes place, and the oil is completely dissolved. On cooling, the product of the reaction is diluted with water, and a light yellow mass precipitates. The precipitate is then placed upon a filter, and washed with water until an acid reaction is no longer noticeable. The dried substance is then crystallized from acetic acid, and shows a melting point of 112° C. Alcohol and ether can be used as crystallizing agents, but are not so good, as the substance crystallized from them will still have a slight yellow color. One would expect, from the analogy between this substance and the aromatic bodies, that a dinitro compound would be formed, yet such is not the case. The mononitrophenylbienylketone, in long, needle-like crystals, is formed. The analysis of the substance is as follows: —

0.0893 gr. of the salt yielded 4.45 c. c. nitrogen, at a temperature of 21° C. and a pressure of 745 mm.

	Found.	Theory for $C_{11}H_7S_2O_3N$.
Nitrogen	5.55	5.29

The results of this work show once more that compounds may be formed from the fat series which show decided characteristics of the aromatic series, and which may be regarded as belonging to it; also, the similarity between biophene and thiophene and benzol has been shown. In conclusion, let me add that the action of phosphorus trisulphide upon thiodilactylic acid has been tried, and a product obtained which shows the isatine reaction, proving that in all probability the dimethylbiophene or bioxene can also be obtained in the same manner as biophene.

MASS. INSTITUTE OF TECHNOLOGY,
April, 1890.

HARCOURT'S PENTANE STANDARD LAMP.

BY H. E. CLIFFORD, INSTRUCTOR IN PHYSICS.

THE great progress which has been made of late years in artificial lighting, particularly the enormous development in lighting by electricity, has given to photometric tests of the different illuminants a considerable importance. In making such tests, we are at once met by the difficulty of securing a satisfactory standard of light for reference. The so-called standard candle, which, for lack of something better, is at present almost universally adopted as a legal standard, is far from constant in its illuminating power, being affected by slight variations in the material and form of the wick, temperature of the photometer room, and numerous other elements.

It seems desirable, however, in the selection of some new standard, that it should be approximately equal to the present standard candle; the expression *so many candle-power* conveying a certain idea, although in most instances a vague one, as to the amount of light which is given by any illuminating source. Constancy of composition in material consumed, effect of temperature and pressure of air upon the intensity of the light, and ease of manipulation, are also to be kept in view in the selection of a legal standard.

The following tests of the Harcourt Pentane Standard Lamp were carried on in April and May, 1888, by Messrs. E. R. Pearson and S. C. Hathaway, Jr., at that time students in electrical engineering at the Institute of Technology. The pentane was prepared by Mr. Pearson from what is known as No. 86 gasolene, and after being refined was of specific gravity 0.6319. The lamps used in the tests were two, one lent by Mr. C. F. Prichard, Superintendent of the Lynn Gas Light Company, the other the property of the Institute. The Pentane Lamp was devised by Mr. Harcourt to replace the Harcourt Air-gas Standard, which is not portable, and, moreover, involves the use of expensive apparatus. The nature of the flame is the same as in the Standard, the essential difference between the two units being that in the Standard the gas is prepared before its application, while in the Lamp it is produced at the instant required. The gas issues from a circular aperture one fourth of an inch in diameter, cut in a brass plug one inch

in diameter and half an inch thick, the height of the flame and number of drops of liquid pentane consumed per minute being easily regulated. In all tests the lamps were allowed to burn either fifteen or thirty minutes before beginning the photometer readings, so that they might become of a constant temperature. The tests were of fifty readings each, unless otherwise specified. In determining the illuminating power in terms of candles, standard sperm candles were used, corrected to a rate of consumption of 120 grains per hour. The lamps were tested against each other, the Lynn lamp being taken as the unit, and were reversed in position. The Bunsen photometer was used in the tests, the photometer room being painted a dull black, and carefully screened to prevent introduction of error by reflection. The photometer bar was 100 inches in length.

In Tables I. and II. are given summaries of the tests of the two lamps against each other, the lamps for Table II. being reversed in position. In Tables III. and IV. the results of comparing the lamps with standard candles and with the Methven Long and Short Slot are given, the Methven being expressed in terms of the Harcourt Lamp. The illuminating power is the mean as determined from fifty observations, the deviation is the average deviation from the mean, and the percentage deviation is given with regard to the mean illuminating power. The difference in illuminating power, as shown on reversal

TABLE I.

HARCOURT *vs.* HARCOURT.

No. of Observations.	Illuminating Power.	Deviation.	Per cent Deviation.
25	1.021	0.014	1.37
25	1.017	0.016	1.57
50	1.008	0.009	0.89
50	1.014	0.011	1.08
50	1.016	0.008	0.78
50	1.034	0.008	0.74
50	1.028	0.010	0.99
50	1.011	0.012	1.16
50	1.018	0.009	0.87

TABLE II.

SAME. — LAMPS REVERSED.

No. of Observations.	Illuminating Power.	Deviation.	Per cent Deviation.
50	1.051	0.012	1.01
50	1.056	0.007	0.61
50	1.053	0.008	0.73
50	1.055	0.007	0.70
50	1.055	0.005	0.51
50	1.055	0.006	0.54
50	1.057	0.005	0.51
50	1.050	0.006	0.61
50	1.056	0.005	0.48

TABLE III. — INSTITUTE HARCOURT.

Methven Long Slot.			Methven Short Slot.		
Illuminating Power.	Deviation.	Per cent Deviation.	Illuminating Power.	Deviation.	Per cent Deviation.
1.836	0.009	0.51	1 907	0.011	0.55
1.879	0.011	0 57	1.942	0.011	0.56

TABLE IV. — LYNN HARCOURT.

Candle A.			Candle B.			Methven Long Slot.			Methven Short Slot.		
Illum. Power.	Deviation.	Per cent Deviat.	Illum. Power.	Deviation.	Per cent Deviat.	Illum. Power.	Deviation.	Per cent Deviat.	Illum. Power.	Deviation.	Per cent Deviat.
1.081	0.030	2.77	1.083	0.012	1.06	2.121	0.016	0.78	2.023	0.010	0.48
1.111	0.016	1.41	1.108	0.012	1.07	2.151	0.019	0.86	2.008	0.020	0.99
1.085	0.014	1.24	1.074	0.011	0.97						
1.015	0.012	1.11	1.054	0.015	1 38						

of the position of the lamps, has not been satisfactorily accounted for.

The Harcourt Pentane Lamp, as a legal standard, would seem to be a satisfactory one so far as mere intensity and constancy of illumination are concerned, although the uncertain quality of pentane and the care required in using the lamp are undoubtedly objectionable.

ROGERS LABORATORY OF PHYSICS,
May, 1890.

RECENT THEORIES ON THE FUNCTION OF THE WHITE BLOOD-CELL.

BY EDWIN O. JORDAN, S. B.

EVER since the discoveries of the celebrated Dutch naturalist, Leeuwenhoek (1632–1723), physiologists have known that ordinary blood is not a mere liquid, as it seems to be, but that in the liquid there are many fairly solid bodies called cells or corpuscles. These are of two principal kinds: the red blood-cells, or hæmacytes; and the white blood-cells, or leucocytes. The red are the more numerous, and give the familiar color to vertebrate blood. In every teaspoonful of human blood there are about 15,000,000,000 red corpuscles, but only 30,000,000 white ones. The blood of clams, lobsters, and nearly all other invertebrates, contains no red cells, but only the white.

The cells are the more important living part of the blood, while the liquid in which they float plays chiefly a mechanical part.

The function of the red cells has for a long time been clearly understood. They are carriers of oxygen from the air to the tissues. These cells owe their color to a peculiar substance called hæmoglobin, which is able to enter very readily into chemical combination with the oxygen of the air met with in the lungs, and to surrender the oxygen quite as readily to the more needy tissues of the body at large. The red corpuscles thus become the middlemen for conveying oxygen from the external air to every inmost nook and corner of the body. The difference in color between arterial and venous blood is dependent upon the more or less thorough oxygenation of the hæmoglobin; the arterial being richly, and the venous poorly oxygenated.

While the office of the hæmacyte has been thus clearly made out, that of the leucocyte has until very recently been exceedingly obscure.

In behavior and in form the leucocyte, or white blood-cell, closely resembles an amœba, — a simple, naked cell of mere protoplasm, a tiny lump of living substance. Like the amœba, it is able to effect changes in its position and its form; like the amœba, it has the power of flowing around and finally engulfing in its substance bodies with which it may come in contact; furthermore, it is able to tear to pieces, dissolve, or *digest* bits of organic material which it has thus surrounded,

this process being known as "intracellular" digestion. The amœba is the lowest animal of which we have any knowledge. It is an "undifferentiated" organism, in the relative sense in which that phrase can be used, remembering that what is called undifferentiated or unspecialized is so only in comparison with higher forms, and that the amœba is enormously complex as compared with simple aggregations of non-living matter.

The leucocyte likewise is an undifferentiated cell; it is the most unspecialized of any cell in the human body, and its structure and appearance at once remind one of the amœba. It is a natural conclusion that the leucocyte must have inherited, along with its primitive structure, the simple physiological peculiarities of its lowly ancestor. Moreover, the leucocytes have very much the appearance and properties of the cells forming the very young body before the different tissues have become recognizable. They alone retain unchanged the original ancestral form; they are cells left over, so to speak, in the process of body-making. They unite in one individual those fundamental properties of contractility, irritability, and secretion, each of which in the adult animal has been taken up and exalted by particular cells at the expense of other functions. The muscle cells are pre-eminently contractile, the nerve-cells pre-eminently irritable, while the cells of the salivary glands, the liver, and the pancreas devote their best energies to secreting and storing up material for future use. To the leucocyte alone does it seem difficult to attribute any one function *par excellence.* Its protoplasm is undifferentiated, crude, raw material as compared with the highly elaborated product in brain, muscle, and gland cells.

What, then, is the function of the white blood-cells? Bearing in mind their simple unspecialized structure, various answers have been given. It has been said, that, "being undifferentiated and specialized to no line of work, they are ready to take up any that comes to hand, and may be compared to the young men in a community who have not yet selected an occupation and are on the lookout for an opening." This view, however, can no longer be strictly and logically held, for it is highly improbable that the leucocytes in an adult animal turn now into muscle cells and now into nerve cells, as some of the young men seeking an occupation choose to be carpenters, and others physicians and lawyers. Indeed, such a view is distinctly contradicted by the history of the different tissues. In the same line of thought is the suggestion — it is hardly more — that since some white blood corpuscles develop into red ones, this may be regarded as their special function.

For the last few years, however, attention has been directed more and more sharply upon a particular attribute of the leucocyte. The leucocyte's power of engulfing various substances has already been alluded to. This must be further emphasized. The leucocytes in a drop of blood will move toward yeast cells, or carmine granules, or indeed almost any solid particles which may be supplied to them, and can be seen with the microscope to surround and envelop the foreign bodies precisely as an amœba would do. As De Bary expresses it: "If a foreign body comes into contact with the surface of the amœboid cell, the latter puts out processes which embrace it and gradually close over it, as the waves close over a drowning animal, so that it lies at last inside the soft cell substance. It may be cast out again at some future time, but it may also suffer decomposition inside the cell, be killed, and disappear."

The possession of this capacity of intracellular digestion has brought the leucocyte into great prominence in several lines of work, one being *the problem of the absorption of fat into the body.* To physiologists it is a well known fact, that of the three great classes of food stuffs, the albuminoids, the starches, and the fats, the entrance of the fats into the body has been most difficult to explain. For while the albuminoids and the starches are soluble in the fluids of the alimentary canal, the fats persist in the form of finely divided particles; so that, while the first two groups of foods may pass through the membrane of the alimentary tract by diffusion, aided perhaps by the suction-pump action of the villi, the fats must pass through as small solid bits.

It is still a vexed question as to just how the passage of the fat is accomplished. Fat globules are found in the alimentary canal; they are also found in the lymph vessels inside the villi. How is the transition effected from one to the other, through a layer of epithelium cells and another layer of connective tissue? It has been supposed by some that the fat passes directly through the columnar epithelium cells lining the walls, and then traverses a system of small canals communicating with one another, and finally with the lymph vessels in the interior of the villus. That is to say, the epithelium cells lining the walls of the intestine grasp the particles of fat and pass them along through the cell substance into the system of canals. On the other hand, it has been maintained by Watney,[1] that the fat does not pass through the substance of the epithelium cells, but between the cells. Other observers hold that both ways of ingress are used.

About 1883, Zawarykin[2] and Schæfer,[3] working independently, came to the conclusion that the fat enters the lymph vessel by no system of

canals, but that the leucocytes bodily transport the particles of fat from the intestine to the lymph cavity of the villus. The leucocytes were actually seen, loaded down with what were apparently fat globules, making their way speedily toward the lymph vessels. Even while admitting that the epithelium cells might play some part in the process, Schæfer yet holds that the leucocytes are the chief means of transportation.

What could be clearer? Fat globules are found in the alimentary canal; the leucocytes, which always swarm in the neighboring tissues after a meal, are also seen to be filled with fat globules; and the same leucocytes, abounding in particles of fat, are found all the way from the canal to the lymph vessel in the villus. Apparently nothing could be simpler. The leucocytes act as beasts of burden, and carry the insoluble fat bit by bit into the body. In so doing, they do what no other cells can do as well. This is their function *par excellence*. As the red blood-cell is the carrier of the food-stuff oxygen, so the white blood-cell is the carrier of the food-stuff fat.

Unfortunately, however, for this interesting and symmetrical hypothesis, there are facts which at present do not allow it to be seriously entertained. One weighty objection is, that the whole matter is based on a case of mistaken identity, and that the fat globules seen in the leucocytes are not fat globules at all. A recent article by Heidenhain[4] effectually disposes of the belief that the globules seen in the leucocytes are fat. Not only are these so-called fat globules susceptible to stain by the aniline dyes, but they persistently refuse to dissolve in ether or xylol. The blunder would seem to have come about through too great reliance on traditional staining methods. Heidenhain gravely says, "As all is not gold that glitters, so all is not fat that stains black with osmic acid."

If Heidenhain's results are confirmed, the main prop of the theory is removed, and the white blood-cell cannot reasonably be considered as the agent by which fat is taken inside the body.

Although on examination of the evidence, *pro* and *con*, the office of fat-carrier must for the present be denied to the leucocyte, there is another and even wider field in which the leucocyte has come to the front. Here, too, the case rests altogether upon the enveloping and digesting qualities of the cell.

The ingenuity of physicians has long been exercised to explain satisfactorily the phenomena of inflammation. The most that can be said is that inflammation is a disturbance of the normal relations between the blood and the tissues. Some of the prominent signs of this disturb-

ance, however, have been exhaustively studied. The pain, caused by tension and pressure upon the sensory nerves; the swelling, redness, and heat brought about by the increased flow of blood to the affected part; the formation of pus, a substance mainly composed of the dead bodies of white blood corpuscles, — are all well known accompaniments of inflammation. When inflammation is produced in the web of a frog's foot, the whole process can be studied in detail with the microscope. In the normal circulation a few white blood corpuscles can be seen sticking to the sides of the small arteries, and passing slowly along by jerks toward the capillaries; but now they collect more thickly upon the walls of the blood-vessels and become more numerous in the capillaries. There is a gathering of the clans of the leucocytes in the neighborhood of the part threatened with inflammation. Very soon they force their way through the cells lining the blood-vessels, and escape into the surrounding tissues, justifying their German name of "wandering cells." The tissue around the veins and capillaries soon becomes crowded with the white corpuscles which have left their normal channels and invaded the inflamed district. These migrating hordes of wandering cells often die in large numbers, and are cast out as *pus*.

The question at once arises, What is the reason for this peculiar migration of the leucocytes? Do they by their death cause inflammation, or do they appear on the scene when mischief is being done by other substances? Are they troublesome seceders, or patriotic defenders?

To answer these questions satisfactorily, we must go back to some famous observations on the behavior of the leucocytes. The occasions upon which the leucocytes display most vigorously their devouring propensities have been studied very thoroughly by Metchnikoff.[5] To Metchnikoff, indeed, belongs the chief place in the development of our knowledge of the leucocytes. He was the first to bring out the suggestive fact, that during the absorption of the tail of a tadpole, amœboid cells are always present in great abundance. These amœboid cells contain scraps of nerve fibre and bits of muscle tissue, and are seen to be making away with the useless tail structure as fast as possible. The fragments enclosed by the leucocytes retain their form for some time, but gradually break up into small globules, and at last merge into the homogeneous cell substance. The same thing is seen during the atrophy of the tadpole's gills. Frog larvæ, moreover, are not the only organisms in which the leucocytes are thus active, for Metchnikoff has described the same process as occurring in the larvæ

of echinodermata, and has shown that the useless organs at each metamorphosis are eaten up by the ever-ready leucocytes. From their possession of this capacity for eating, the leucocytes are often called *phagocytes*, or eating cells. At any inflamed or injured spot, the amœboid cells collect and greedily devour the particles of dead tissue. Whenever and wherever any of the cells of the body die, the phagocytes hasten to remove the corpses. This point is practically certain, that the phagocytes are the scavengers of the organism, the removers of waste and useless material from the body. Have they also a still higher function? Are they the defenders of the organism?

It has long been known that, when a foreign body is introduced into a living blood-vessel, one of the first events is the collection of leucocytes around it. A needle thrust through the wall of a blood-vessel will bring the leucocytes clustering thickly around its point. There is apparently a swarming of the white blood-cells to oppose the invading substance. There seems something akin to this in the case of inflammation also, something more than a mere hastening to remove worn-out tissue, — almost an actual resistance to a hostile influence. The leucocytes appear to resent the presence of anything which can cause harm, and to bend their energies towards removing the offending body; attempting, as it were, to protect the body of the individual as militia do the body politic. Metchnikoff even goes so far as to say, that the process of inflammation is a struggle between irritant bodies and white blood corpuscles.

The relation between the phenomena of inflammation and the invasion of the organism by living parasites is well known. In a paper now become classic, Metchnikoff describes a singular disease that sometimes afflicts the Daphnia, or water-flea. Some of these little creatures, which he kept in a tank in his room for purposes of study, became covered with spores, or conidia, which gained an entrance to the body of the crustacean, multiplied, and were carried by the blood current all over the body. The leucocytes in the mean time do not remain idle spectators of this hostile inroad, but speedily attack and devour the invading spores. If one of the conidia prove too much for a single leucocyte to handle, others join in the assault, and fuse into an invincible "giant cell." The conflict is to the bitter end. "If the leucocytes finally overpower the spores, the Daphnia lives; if not, the conidia completely overrun the crustacean, and death is the result."

According to Metchnikoff, exactly the same struggle takes place whenever an animal body is invaded by bacteria of any sort, as, for example, by the bacilli of anthrax, or splenic fever. In animals such

as frogs and lizards, which are not "susceptible" to anthrax, anthrax bacilli if introduced into the blood are devoured by the phagocytes. The same thing happens when susceptible animals are inoculated with anthrax bacilli which have been "attenuated" or weakened to a harmless condition. But when virulent anthrax bacilli are introduced into the blood of an animal susceptible to the disease, it is only in exceptional cases that the bacteria are taken up by the leucocytes. Metchnikoff therefore asserts, that the anthrax bacillus can cause no harm if it is absorbed and destroyed by the white blood-cells, but that it is dangerous if this does not happen. In other words, the reason that the anthrax bacillus does not do harm is because the white blood-cell envelops and digests it. If for any cause the white blood-cell is unable to perform this duty, either through the high virulence — whatever that may mean — of the bacilli, or through its own incompetence, the bacilli may effect serious and even fatal ravages. This is the essence of the phagocyte theory as advocated by Metchnikoff. When pathogenic bacteria are introduced into the blood of an animal, there ensues a struggle to the death between the bacteria and the leucocytes. If the leucocytes succeed in overpowering the bacteria, the animal recovers; if they fail in this, the bacteria thrive and multiply, and the animal finally dies.

Stated in its most metaphorical form: "If we summarize the story, it should be likened to a battle. The leucocytes are the defending army, their roads and lines of communication the blood-vessels. Every composite organism maintains a certain proportion of leucocytes as representing its standing army. When the body is invaded by bacilli, bacteria, micrococci, chemical or other irritants, information of the aggression is telegraphed by means of the vaso-motor nerves [*sic!*], and leucocytes rush to the attack; reinforcements and recruits are quickly formed to increase the standing army, sometimes twenty, thirty, or forty times the normal standard. In the conflict, cells die, and are often eaten by their companions; frequently the slaughter is so great that the tissue becomes burdened by the dead bodies of the soldiers in the form of pus, the activity of the cell being testified by the fact that its protoplasm often contains bacilli, etc., in various stages of destruction. These dead cells, like the corpses of soldiers who fall in battle, later become hurtful to the organism they in their lifetime were anxious to protect from harm; for they are fertile sources of septicæmia and pyæmia, — the pestilence and scourge so much dreaded by operative surgeons." * Though perhaps rather bellicose, the figure

* J. B. Sutton, An Introduction to General Pathology, p. 127.

just drawn is not unnatural. The phagocyte theory is almost captivating in its dramatic simplicity.

There are, however, many biologists who do not agree with Metchnikoff's interpretation of his observations, although accepting the observations themselves as undoubtedly correct. As to the facts, there can no longer be any question. It is as certain as any such thing can be, that bacteria of various kinds have been seen engulfed in the substance of the white blood corpuscles. Metchnikoff's experiments have been repeated and his statements confirmed time and again by himself, by Wyssokowitsch,[6] Hess,[7] Nuttall,[8] and other competent observers.

The point at issue is simply this: Do the leucocytes march upon and devour the living bacteria? or do the bacteria die in the blood because they are in other respects in unfavorable circumstances, and then, when the bacteria are already dead, do the leucocytes step in and devour the corpses? Are the leucocytes brave soldiers, or only faithful scavengers? The mere fact that bacteria have been seen inside a white blood-cell of course proves nothing. Metchnikoff has sketched from observation white blood corpuscles in the act of enveloping anthrax bacilli, and other corpuscles containing anthrax bacilli in various stages of decomposition. Yet clearly in these cases it cannot be determined whether the leucocytes attacked the bacteria while alive, or simply engulfed them when dead.

There are, nevertheless, some considerations which appear to favor the idea that the leucocyte is a fighting cell. It is well known, for instance, that at ordinary temperatures frogs are not susceptible to anthrax, and, though inoculated with virulent bacilli, remain perfectly healthy. If, however, the frogs are kept at about 85° F., the leucocytes in the frogs' blood no longer take up the bacilli as before, and the animals soon become infected with the disease. Metchnikoff explains the fact that the anthrax bacilli are more potent at the higher temperature by the hypothesis that they have been accustomed to deal with and overcome the leucocytes of warm-blooded animals, and therefore are at a disadvantage in combating the leucocytes of the cold-blooded frog. His opponents quickly dispose of this explanation by retorting that the anthrax bacilli are never able to thrive at a low temperature, but soon die in the cold blood of a frog, and are then consumed by the phagocytes. At a higher temperature, the anthrax bacilli are able to exercise their full virulence, and the leucocytes, although also undoubtedly quickened by the warmth, are not able to cope with the active living bacteria, and the latter win a signal victory.

Other facts brought forward in favor of the theory are, that, if an animal be inoculated with a small quantity of bacteria, there will afterwards be found in the blood a much larger number of leucocytes than at first, seeming to show a strengthening of forces to meet the attack of the enemy. It has also been stated, that anthrax bacilli which have been killed by boiling are not so quickly taken up by the leucocytes as are those injected alive,— a fact that would of course indicate that the leucocytes do not trouble themselves about dead, and consequently innocuous bacteria. This would seem materially to strengthen the cause of Metchnikoff and his followers.

On the other hand, it has never been proved experimentally that bacteria have been destroyed by phagocytes, and by phagocytes alone. Baumgarten,[9] Bitter,[10] and others, have urged this utter lack of positive evidence, and have demonstrated how insecure is the basis of the phagocyte theory, judged on this point alone. There is, in addition, a certain kind of evidence of the existence of hostile influences in the body outside of the leucocytes. A number of observations have shown that anthrax bacilli have often suffered some damage before they became the prey of the phagocytes. Some very suggestive experiments by Christmas-Dirkinck-Holmfeld[11] showed that only comparatively few bacteria were taken up by the leucocytes, and that by far the greater number of bacteria were destroyed outside the cell. He proved conclusively that, even if the phagocytes did play some part in the struggle of the organism against harmful foreign bodies, they were not the sole defenders, — theirs indeed was not the chief *rôle*. There are manifestly other influences in the body hostile to bacteria.

This bacteria-destroying influence has been thought to be resident in the blood, the belief being based on the researches of Nuttall,[8] Buchner,[12] Nissen,[13] and others. These observers proved that blood taken from the body possessed germicidal properties, and that blood serum, freed from all corpuscles, could destroy even virulent anthrax bacteria. This remarkable property is lost on heating the serum to 55° C., but at ordinary temperatures persists for days. This fact was thought to give the death-blow to the phagocyte theory, because if blood serum *per se* was able to destroy bacteria, there was clearly no need for supposing that the leucocytes voluntarily attacked living bacteria. It might be held more reasonably that the leucocytes simply took up the bacteria which were already killed or weakened by the influences shown to exist in blood serum.

Very recently an exceedingly important paper by Lubarsch[14] has appeared, in which the author urges that, although the blood *outside*

the body is able to destroy bacteria, this has not been proved true of the same blood *inside* the body. Indeed, his experiments show very plainly that a great difference exists. In one experiment, for example, a single drop of rabbit's blood, when removed from the body, destroyed 53,700 bacilli, but all the blood of the same animal when inside the body could not kill 16,430 bacteria with which the animal was inoculated; on the contrary, the bacteria multiplied, and the animal died. Lubarsch attributes this startling difference to the different conditions of nutrition existing inside and outside the animal body. However this may be, there seems no reason for doubting the fact, that in the living animal the substances normally present in the blood exert no perceptible injurious effect upon living bacteria.

Lubarsch also records a number of experiments bearing more closely upon the phagocyte theory, and concludes from their results, that, although leucocytes do occasionally take up living bacteria, there is no such wholesale destruction of the bacteria by the white blood corpuscles as supposed by Metchnikoff's theory. He recognizes rather an influence proceeding *directly from the body cells*, which not only prevents the multiplication of the bacteria, but may even kill them.

On the whole, the burden of proof rests decidedly upon the advocates of the phagocyte theory. We are plainly not in a position at the present time to frame an adequate theory of immunity. There is no convincing evidence of any struggle of the leucocytes with the living bacteria. The existence of the cell militant cannot as yet be recognized. On the contrary, there is a large and increasing amount of testimony against the possession of the soldier function by the white blood-cell.

While the theory that the leucocyte is the defender of the organism, and the theory that it is the agent by which fat is taken inside the body, have been by far the most prominent of recent views concerning the function of the white blood-cell, there is still another way by which it has been thought that the leucocyte might make good its claim to be considered a helpful member of the organism. This is Cohnheim's theory of the formation of scar-tissue. Cohnheim, supported by Ziegler and other accurate observers, held that the leucocytes which wandered into an inflamed area were not only the source of the pus cells when pus appeared, but were also the formative cells for the new tissue, if any new tissue were formed. This view has always been more or less opposed by some investigators in this field, and has recently been discussed afresh by Sherrington and Ballance.[15] These observers have

made a number of careful experiments on the formation of scar-tissue, and conclude that the theory that scar-tissue is produced by the transformation of leucocytes should be abandoned. "Our observations yield no support to Cohnheim's view of the genesis of cicatricial tissue from leucocytes."

The present seems indeed to be a time when the leucocyte is being denied what few virtues it was once allowed to possess, for Looss [16] has controverted *in toto* Metchnikoff's fundamental observation, that the leucocytes are the active agents in destroying the useless tissues of animals, — as the tail of a tadpole at the metamorphosis period. "Not only the muscles and nerves, but also the other tissues of the batrachian tail, are destroyed independently, and are digested by the fluids of the body without the help of the leucocytes."

Thus it is evident that, although the last few years have materially advanced our knowledge of the white blood-cell, and given rise to many ingenious theories concerning its function, we cannot accept any one of these theories as the whole truth and nothing but the truth. It is yet impossible for the physiologist to state positively the function of the white blood-cell.

1 **Watney**. The Minute Anatomy of the Alimentary Canal. (Phil. Trans., Vol. CLXVI., 1878.)

2 **Zawarykin**. Ueber die Fettresorption im Dünndarm. (Pflüger's Archiv, Bd. XXXI., 1883.)

3 **Schæfer**. Ueber die Fettresorption im Dünndarm. (Pflüger's Archiv, Bd. XXXIII., 1884.)

4 **Heidenhain**. Beiträge zur Histologie und Physiologie der Dünndarmschleimhaut. (Pflüger's Archiv, Supplement, Bd. XLIII.)

5 **Metchnikoff**. Intracellulare Verdauung. (Arbeiten aus dem zoologischen Institut zu Wien, Bd. V., 1883.)

Untersuchungen über mesodermale Phagocyten einiger Wirbelthiere. (Biol. Centralbl., III., No. 20.)

Sur la Lutte des Cellules de l'Organisme contre l'Invasion des Microbes. (Annales de l'Institut Pasteur, 1887, p. 321.)

Recherches sur la Digestion intracellulaire. (Annales de l'Institut Pasteur, 1889, p. 25.)

Études sur l'Immunité. (Annales de l'Institut Pasteur, 1889, p. 289.)

6 **Wyssokowitsch**. Ueber die Schicksal der in's Blut injicirten Mikroorganismen im Körper der Warmblüter. (Zeit. für Hygiene, Bd. I. p. 3, 1886.)

7 **Hess**. Untersuchungen zur Phagocytenlehre. (Virch. Archiv, Bd. CIX. u. CX.)

8 **Nuttall**. Experimente über die bakterienfeindliche Einflüsse des thierischen Körpers. (Zeit. für Hygiene, Bd. IV. p. 353.)

9 **Baumgarten**. Lehrbuch der pathologischen Mykologie, 1888, p. 90 *et seq.*

10 **Bitter**. Kritische Bemerkungen zu Metschnikoff's Phagocytenlehre. (Zeit. für Hygiene, Bd. IV. p. 318.)

11 **Christmas-Dirkinck-Holmfeld**. Ueber Immunität und Phagocytose. (Fortschr. d. die Med., Bd. V. pp. 401, 583.)

12 **Buchner** *et al.* Untersuchungen über die bacterienfeindlichen Wirkungen des Blutes und Blutserums. (Archiv für Hygiene, Bd. X. Heft 1, p. 84; Heft 2, p. 121.)

13 **Nissen.** Zur Kenntniss der bakterientödtenden Eigenschaften des Blutes. (Zeit. für Hygiene, Bd. VI. p. 487.)

14 **Lubarsch.** Ueber die bakterienvernichtenden Eigenschaften des Blutes und ihre Beziehungen zur Immunität. (Centralblatt für Bakteriologie, Bd. VI. Nos. 18, 19, 20, pp. 481, 529.)

15 **Sherrington and Ballance.** On Formation of Scar-Tissue. (Journal of Physiol., Vol. X. No. 6, p. 550.)

16 **Looss.** Ueber die Beteiligung der Leukocyten an dem Zerfall der Gewebe im Froschlarvenschwange während der Reduktion desselben. (Leipzig, 1889.) (Abs. Biol. Centralblatt, Bd. IX. p. 595, 1889.)

ON THE DETERMINATION OF CARBONIC ACID IN WATER, AND THE BICARBONATES OF LIME AND MAGNESIA.

BY ALLEN HAZEN, PH. B.

I HAVE tried various methods for the determination of carbonic acid in water, depending upon the precipitation of calcium carbonate, and also by boiling off and weighing in potash bulbs. The results obtained were not satisfactory; not only did the different processes fail to give concordant results, but duplicate determinations by the same process seldom agreed. The reason for these unsatisfactory results, as I shall show, is loss of carbonic acid during the collection of the sample and the measuring out of portions.

To overcome this difficulty, I have proceeded as follows. A graduated flask, having a considerable space in the neck above the mark, is filled from a tube passing to the bottom of the flask, and at least several hundred cubic centimeters of water are allowed to pass through and overflow the flask. This is easily done when the water is taken from a tap. In other places a different arrangement must be used. The precautions required are precisely the same as for the collection of samples for dissolved oxygen; the water must not at any time come in contact with air, or any other gas. The water in the flask is rapidly brought to the mark by means of a siphon, and lime-water, or caustic soda free from carbonic acid is at once added in such quantity that when mixed it will color phenolphthalein. A large excess is to be avoided. After mixing, the contents of the flask may be poured out without danger of loss, and the carbonic acid determined by well known methods depending upon the precipitation of calcium carbonate.

It is much easier, however, to titrate with acid, using first phenolphthalein, and after the pink color is discharged using methylorange as an indicator. The difference between the quantities of acid required with the two indicators represents one half the total carbonic acid. Instead of proceeding in this way it is found to be more convenient to add standardized alkali in slight excess, and titrate back with acid, using phenolphthalein as an indicator. Another portion of water is titrated directly with acid using methylorange. In this case the sum

of the acid used with methylorange, and the acid equal to the alkali required with phenolphthalein is equal to one half the carbonic acid.

This process depends upon the neutrality of bicarbonates to phenolphthalein. Sutton[1] makes use of this titration for the determination of carbonate in presence of caustic alkali. To determine the accuracy of the process, titrations were made of a solution of ignited sodium carbonate, and of a mixture of this solution with water, and with other salts. The water used was made free from carbonic acid by prolonged aeration with air which had first passed through caustic potash. A few results are as follows: —

Na_2CO_3 Solution.	Other Salt.	Total Volume.	$\frac{N}{20}$ H_2SO_4.		CO_3 found.	CO_2 taken.	Remarks.
			Phenolphthalein.	Methylorange.			
		c. c.	c. c.	c. c.	mgs.	mgs.	
		100	0	0.05	0.11	..	Distilled water.
c. c.							
0.5	....	100	0.25	0.55	0.66	0.54	
5.0	....	20	3.00	4.90	4.18	5.4	Acid added rapidly with little stirring.
5.0	....	50	3.00	4.90	4.18	5.4	" " "
5.0	....	100	2.60	4.90	5.06	5.4	" " "
5.0	....	5	2.80	4.87	4.55	5.4	Acid added slowly with constant stirring.
5.0	....	10	2.65	4.88	4.69	5.4	" " "
5.0	....	20	2.50	4.90	5.28	5.4	" " "
5.0	....	50	2.45	4.90	5.39	5.4	" " "
5.0	....	100	2.42	4.90	5.45	5.4	" " "
5.0	1.0 gr. $CaCl_2$	100	2.30	4.90	5.72	5.4	" " "
5.0	0.1 gr. "	100	2.45	4.90	5.39	5.4	" " "
5.0	1.0 gr. $MgCl_2$	100	2.45	5.00	5.61	5.4	" " "
5.0	0.1 gr. "	100	2.45	4.95	5.50	5.4	" " "
5.0	1.0 gr. NH_4Cl	100	0	4.90	..	5.4	" " "
5.0	0.1 gr. "	100	1.60	4.95	7.37	5.4	" " "
5.0	0.01 gr. "	100	2.45	4.95	5.50	5.4	" " "

[1] Volumetric Analysis, 5th ed., p. 46.

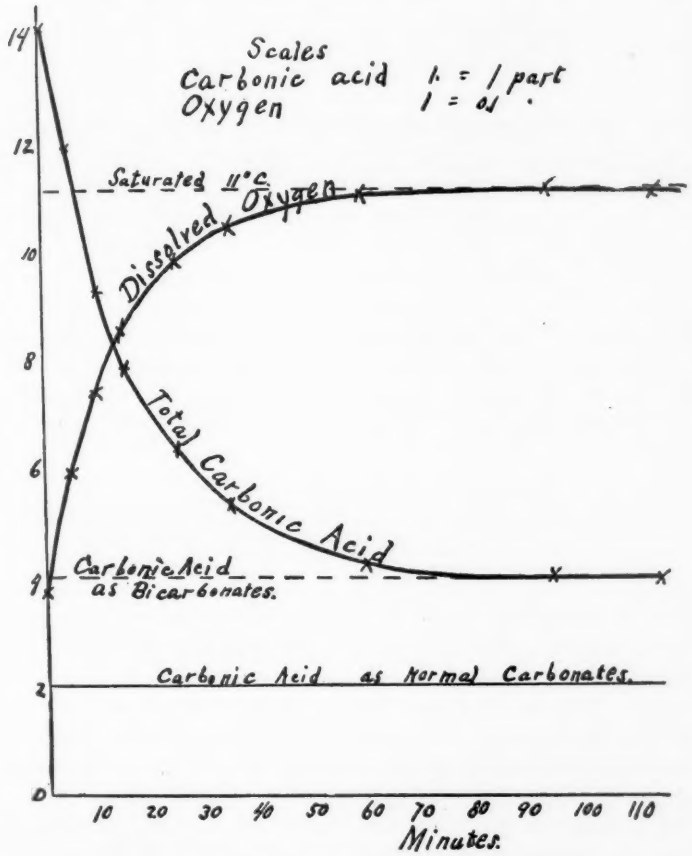
The low results with a concentrated solution of sodium carbonate are due to the loss of carbonic acid during titration from that portion of the surface of the liquid which is acid. This loss is greatly reduced by keeping the liquid thoroughly mixed, and by using a not too concentrated solution. The presence of calcium and magnesium chloride does not influence the result. Even with one per cent, fairly good results were obtained. Ammonia does not influence the result when present in as large quantity as is found in water or sewage. With a very large amount the result is too high.

This process thus gives good results, under suitable conditions, with sodium, calcium, magnesium, and ammonium carbonates. We may then fairly assume that the results obtained for waters are correct, especially when the alkali used is only in slight excess, as then there is almost no chance for loss of carbonic acid during the titration, which is by far the greatest source of error.

Water at 15° will dissolve about its own volume of carbonic acid, or 200 parts per 100,000 by weight. Atmospheric air contains only 4 parts of carbonic acid in 10,000, and therefore water saturated with air will contain only 0.08 of a part per 100,000, — a quantity too small to be determined. We should expect, then, that a water containing free carbonic acid would very rapidly lose it on exposure to the air, and this is the case. I have found that water which, taken from a tap in the manner stated, has 15 parts per 100,000 of free carbonic acid, will not show more than 8 or 10 parts when a bottleful is taken, and flasks are filled from it at once, by pouring. Naturally, no two results will agree; the more exposure, the lower will be the result. With the process described, it is possible to obtain an indefinite number of closely agreeing determinations.

By prolonged exposure, the carbonic acid is reduced to twice the equivalent of the free base present. This is well shown by the following experiment. A large bottle was filled with a natural water containing much carbonic acid and but little oxygen. A slow and regular stream of air was blown through, and, at frequent intervals, samples were siphoned out for the determination of carbonic acid and dissolved oxygen. The results obtained during the first two hours are shown by the following diagram.

Experiments have been made in the same way, using distilled water and solutions of sodium, calcium, magnesium, and ammonium carbonates in water with an excess of carbonic acid. The results are almost exactly like that shown by the diagram, and need not be given here. By continuing the air current for a very long time, a slight addi-



tional amount of carbonic acid is removed, and the water will then color phenolphthalein. The rate of removal of carbonic acid, after reaching the point where it is equivalent to twice the base, is many times slower than before. To this point the rate is equal to the rate of removal from distilled water containing as much carbonic acid as there is here excess over twice the equivalent of base.

These experiments show the existence of real bicarbonates of calcium and magnesium. They also indicate that these bicarbonates are slightly dissociated by water, as is also sodium bicarbonate in equal dilution.

LAWRENCE EXPERIMENT STATION,
Mass. State Board of Health.

DATA AND PLOTS OF VARIOUS INCANDESCENT LAMPS, TOGETHER WITH AN IMPROVED METHOD OF TESTING.[1]

PART II.

BY WM. L. PUFFER, INSTRUCTOR IN PHYSICS.

THE object of this investigation was to determine the efficiencies of various makes of incandescent lamps. The method used was similar to, but in all respects an improvement upon, that used in 1885 by the Franklin Institute. The component measurements to be made are these: —

1. The current passing through the lamp.
2. The difference of potential between the lamp terminals.
3. The required photometer readings.

The current was determined by a Thomson current galvanometer placed in series with the lamp and an adjustable resistance for regulating the potential. The difference of potential was determined by a Thomson potential galvanometer of 7,500 ohms resistance connected with the terminals of the lamp. Great constancy of potential was rendered possible by the use of an automatic governor designed and built by the department. The current readings were corrected by deducting the current flowing through the potential galvanometer.

(The description of holder and method of working are omitted, as they are similar to those given in the first part of the paper. — W. L. P.)

The following varieties of lamps were tested in the order given: —

Lamps	C, D, M,	Sawyer-Man,	110	volts,	16	c. p.,	marked	16	c. p.,	A 3–16 c. p. A 4
"	A, B, L,	"	60	"	16	"	"	16	"	B 4
"	I, J, K,	Weston,	110	"	16	"	"	16	"	110 volts, B. B. G.
"	E, F, N,	Edison,	110	"	16	"	"	Edison's patents, 16 c., 3.1		
"	R, S, T,	"	93	"	16	"	"	"	"	16 c.
"	O, P, Q,	"	85	"	16	"	"	"	"	16 c.
"	G, H,	"	110	"	32	"	"	"	"	32 c., 3.1

[1] From Graduation Thesis on the Distribution of Light around Incandescent Lamps, with Efficiency Measurements, by Henry M. Hobart and Earl W. Gannett, Massachusetts Institute of Technology. These results and plots are taken directly from the thesis, with no

Three separate lamps of each kind were tested; two separate tests by different observers were made on each lamp, and their means taken to represent the values for that particular type of lamp.

Therefore, forty-two tests were made on twenty-one lamps of seven varieties. Every final result is the mean of the results for three separate lamps and for six separate tests. Every point plotted on the diagrams is the mean of twenty-four settings of the photometer disk. Four careful determinations of the value of "H" were made by the Kew magnetometer at the outset. The four results and their mean are .1747, .1751, .1744, .1748; mean, .1748.

The accuracy of the results was insured by checking, at three different stages of the work, the means of the results and the results of the means.

The following table and the first table on page 189 are taken from the thesis to show methods of combining results and the agreements.

PHOTOMETRIC OBSERVATIONS ON LAMP J, BEING A MEAN OF OBSERVATIONS J, BY E. W. G., AND J_2, BY H. M. H.

Angle.	Horizontal 0°.	Vertical 0°.	Vertical 45°.	Vertical 90°.	Vertical 135°.
0	14.90	15.13	24.28	25 68	20 46
30	20 13	15.13	22.63	24.25	18.45
60	25 70	11.93	15.41	17.73	13 33
90	27.73	8 58	8 85	9 18	9 00
120	23.23	11.25	15.60	18 18	13 81
150	17.58	13.60	21.53	25.15	18.88
180	14 91	15.38	24.45	27.10	20.40
210	20 03	15.13	21.83	22.73	18 13
240	25.60	11.46	14.78	14.13	10.53
270	27.83	0	0	0	0
300	22.86	9 03	12 08	12.46	12.50
330	17.53	14.28	21.03	22.71	18 03
0	15 13	15.18	24.23	25.88	20 55

correction or recalculations, which seemed unnecessary. I have added a few tables and words, which are in all cases accompanied by my initials. The work was intended for, and is, an extension of previous work, under far better conditions, and with the latest lamps obtainable. — WM. L. PUFFER. Reprinted from the Electrical Engineer, New York, April 2, 1890.

RESULTS OF OBSERVATIONS OF MESSRS. GANNETT AND HOBART, '89. — TABULATED AND ENLARGED. (W. L. P.)

Lamp. — 1888-89.	Mean standard reading.	Mean spherical c. p.	Spherical reduction factor.	Mean horizontal c. p.	Horizontal reduction factor.	Spherical divided by horizontal.	Volts.	Amperes.	Watts.	Watts per spherical c p.	Watts per horizontal c. p.	Lamps per electrical horse-power.	Mean spher. cand. per electric'l horse-p.	Mean hor. can. per electric'l horse-p.
Edison 85-volt, 16 c. p.	12.06	10.48	0.873	13.30	1.108	0.789	85.00	0.6200	52.70	5.04	3.98	14.14	148	188
Edison 93-volt, 16 c. p.	13.38	12.65	0.947	15.83	1.185	0.800	93.00	0.7240	67.33	5.32	4.26	11.07	140	175
Edison 110-volt, 16 c. p.	14.57	12.34	0.851	16.10	1.111	0.767	110.0	0.4552	50.07	4.07	3.12	14.90	184	240
Edison 110-volt, 32 c. p.	27.21	24.08	0.890	30.39	1.122	0.793	110.0	0.8507	93.58	3.89	3.08	7.97	192	242
Weston 110-volt, 16 c. p.	16.50	20.92	1.347	24.81	1.592	0.845	110.0	0.6451	70.97	3.47	2.93	10.51	220	261
Sawyer-Man 60-volt, 16 c. p.	23.54	19.06	0.810	23.39	0.994	0.815	60.00	0.9521	57.12	3.00	2.45	13.06	249	306
Sawyer-Man 110-volt, 16 c. p.	28.17	23.57	0.835	28.58	1.010	0.826	110.0	0.6724	73.97	3.17	2.62	10.09	239	288

EDISON 110 VOLT, 16 CANDLE-POWER, 3.1 WATTS. — MEAN RESULTS OF LAMPS E, F, N, AND THE MEAN OF THESE THREE MEANS.

	E.	F.	N.	Mean.
Mean standard reading	16.07	13.08	14.57	14.57
Mean spherical candle-power .	12.49	11.49	13.03	12.34
Spherical reduction factor . .	0.779	0.879	0.895	0.851
Mean horizontal candle-power .	16.16	15.33	16.80	16.10
Horizontal reduction factor . .	1.007	1.172	1.152	1.111
Ratio of spher. c. p. to hor. c. p.	0.774	0.751	0.776	0.767
Volts	110.0	110.0	110.0	110.0
Amperes	0.4705	0.4377	0.4574	0.4552
Watts	51.76	48.15	50.31	50.07
Watts per spher. candle-power .	4.156	4.191	3.862	4.070
Watts per hor. candle-power .	3.216	3.147	2.996	3.120
Resistance (hot)	233.8	251.3	240.5	241.9

1889 LAMPS IN ORDER OF EFFICIENCIES EXPRESSED IN TERMS OF WATTS PER SPHERICAL CANDLE-POWER. (W. L. P.)

	Maker.	Voltage.	Rated candle-power.	Watts per candle-power.	Candles per electrical horse-power.
1	Sawyer-Man	60	16	3.00	249
2	"	110	16	3.17	239
3	Weston	110	16	3.47	220
4	Edison	110	32	3.89	192
5	"	110	16	4.07	184
6	"	85	16	5.04	148
7	"	93	16	5.32	140

1889 Lamps in Order of Efficiencies expressed in Terms of Watts per Horizontal Candle-power. (W. L. P.)

	Maker.	Voltage.	Rated candle-power.	Watts per candle-power.	Candles per electrical horse-power.
1	Sawyer-Man	60	16	2.45	306
2	"	110	16	2.62	288
3	Weston	110	16	2.93	261
4	Edison	110	32	3.08	242
5	"	110	16	3.12	240
6	"	85	16	3.98	188
7	"	93	16	4.26	175

1889 Lamps. Showing Candle-power actually given out in Spherical Candle-power in Percentage of Rated Candle-power. (W. L. P.)

	Maker.	Voltage.	Rated candle-power.	Per cent.
1	Sawyer-Man	110	16	147
2	Weston	110	16	131
3	Sawyer-Man	60	16	119
4	Edison	93	16	79.1
5	"	110	16	77.1
6	"	110	32	75.2
7	"	85	16	65.5

1889 Lamps. Showing Candle-power actually given out on the Horizontal Circle in Percentage of the Rated Candle-power. (W. L. P.)

	Maker.	Voltage.	Rated candle-power.	Per cent.
1	Sawyer-Man	110	16	178
2	Weston	110	16	155
3	Sawyer-Man	60	16	146
4	Edison	110	16	101
5	"	93	16	98.9
6	"	110	32	95.0
7	"	85	16	83 1

Comparison of Four last preceding Tables, showing Position of Lamp when compared according to these Methods. (W. L. P.)

Maker.	Voltage.	Rated candle-power.	Watts per spherical c. p.	Watts per horizontal c. p.	Per cent spherical c. p.	Per cent horizontal c. p.
Sawyer-Man	60	16	1	1	3	3
"	110	16	2	2	1	1
Weston	110	16	3	3	2	2
Edison	110	32	4	4	6	6
"	110	16	5	5	5	4
"	85	16	6	6	7	7
"	93	16	7	7	4	5

In addition to these results, it is necessary to know three more things before deciding which lamp is the best one, and the cheapest to use: 1. cost of new lamps; 2. life of lamp when burned at proper voltage; 3. fall of candle-power due to increase in the life of lamp.

Under the cost of lamps must be reckoned the percentage of broken lamps which are always found in a batch of new lamps, the number which break instantly or within a few minutes of the time the current is first turned on, and those with defective fittings or otherwise in such condition that they cannot be burned. What experience I have had with lamps of the above kinds points to the conclusion, that from three to five per cent is about the proportion of loss; from actual count on one of the makes I find that I lose about five per cent of every new lot. This loss makes a very material difference in the cost of a lamp, and must be taken into account. As to the life of lamp and fall of candle-power with age, I have no figures ready for publication. It is a very open question whether a lamp's life ends when it ceases to give say 50 per cent of its original light, or when it becomes blackened, or when the filament actually breaks. From the moment the current is first turned on, the lamp begins to depreciate, sometimes increasing and sometimes diminishing in candle-power, or even both, until the filament finally breaks. I believe in a lamp that maintains its original light, or possibly increases it, until it has run a number of hours, and then fails rapidly and breaks, and not in a lamp which is at rated candle-power only for the first few hours of its life, and then dies by slow consumption at the end of its guaranteed life with a light only perhaps five or ten per cent of its original brightness, having lived as a "red-hot hair-pin" for the last half of its life.

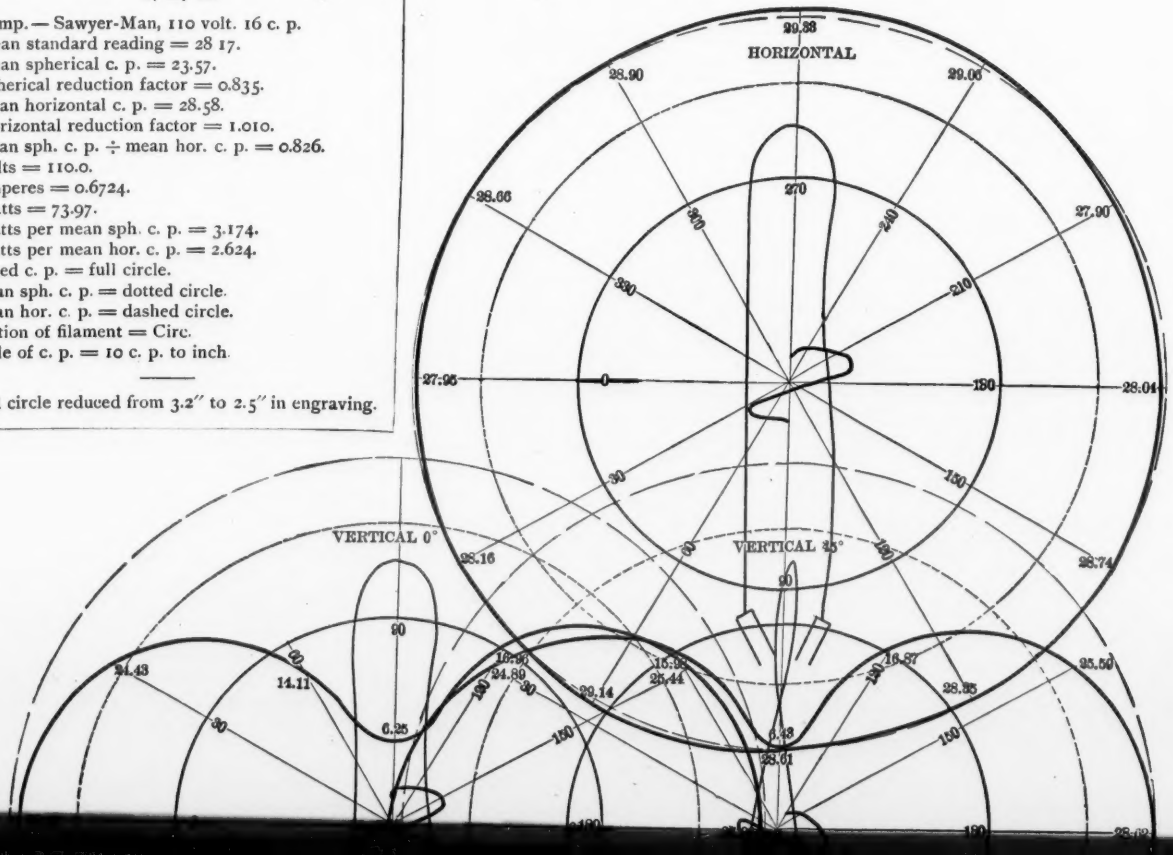
It should be stated that all of the Weston and Sawyer-Man lamps were bought in Boston of the supply companies out of stock, and were in their original wrappers when taken for test. No questions were asked as to the use to which the lamps were to be put. Of the Edison lamps tested, the 110 volt 16 c. p. lamps came out of a stock of lamps on hand for general lighting use, but the rest were ordered by the local Edison company from the lamp factory, knowing that they were for testing purposes. Lamps could not be bought without a declaration of the purpose for which they were wanted.

Rogers Laboratory of Physics,
Mass. Inst. of Technology, *December*, 1889.

C, D, M.

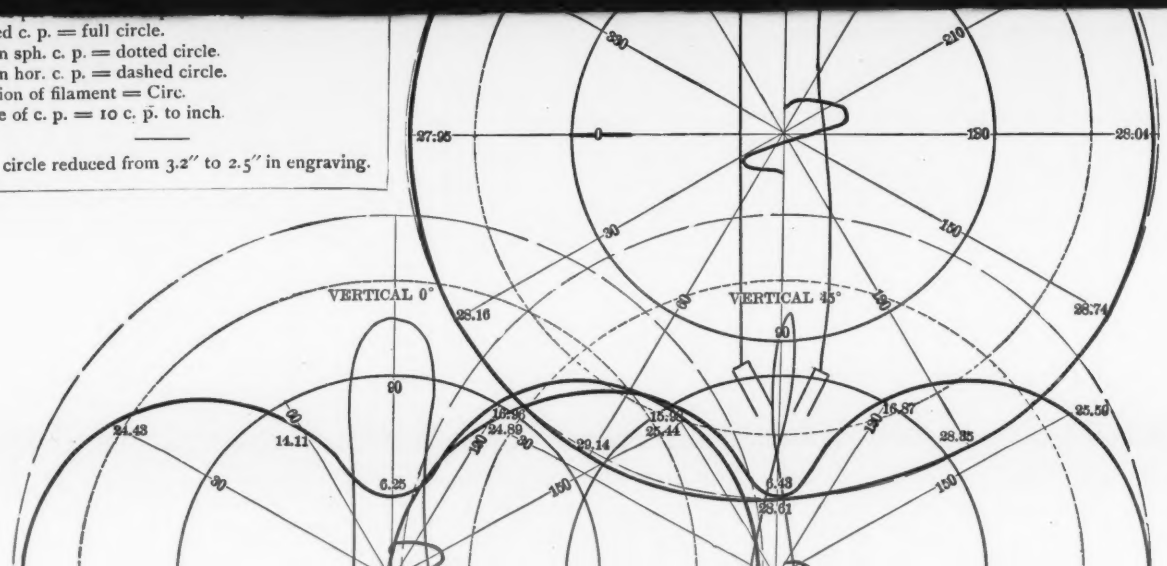
Lamp. — Sawyer-Man, 110 volt. 16 c. p.
Mean standard reading = 28 17.
Mean spherical c. p. = 23.57.
Spherical reduction factor = 0.835.
Mean horizontal c. p. = 28.58.
Horizontal reduction factor = 1.010.
Mean sph. c. p. ÷ mean hor. c. p. = 0.826.
Volts = 110.0.
Amperes = 0.6724.
Watts = 73.97.
Watts per mean sph. c. p. = 3.174.
Watts per mean hor. c. p. = 2.624.
Rated c. p. = full circle.
Mean sph. c. p. = dotted circle.
Mean hor. c. p. = dashed circle.
Section of filament = Circ.
Scale of c. p. = 10 c. p. to inch.

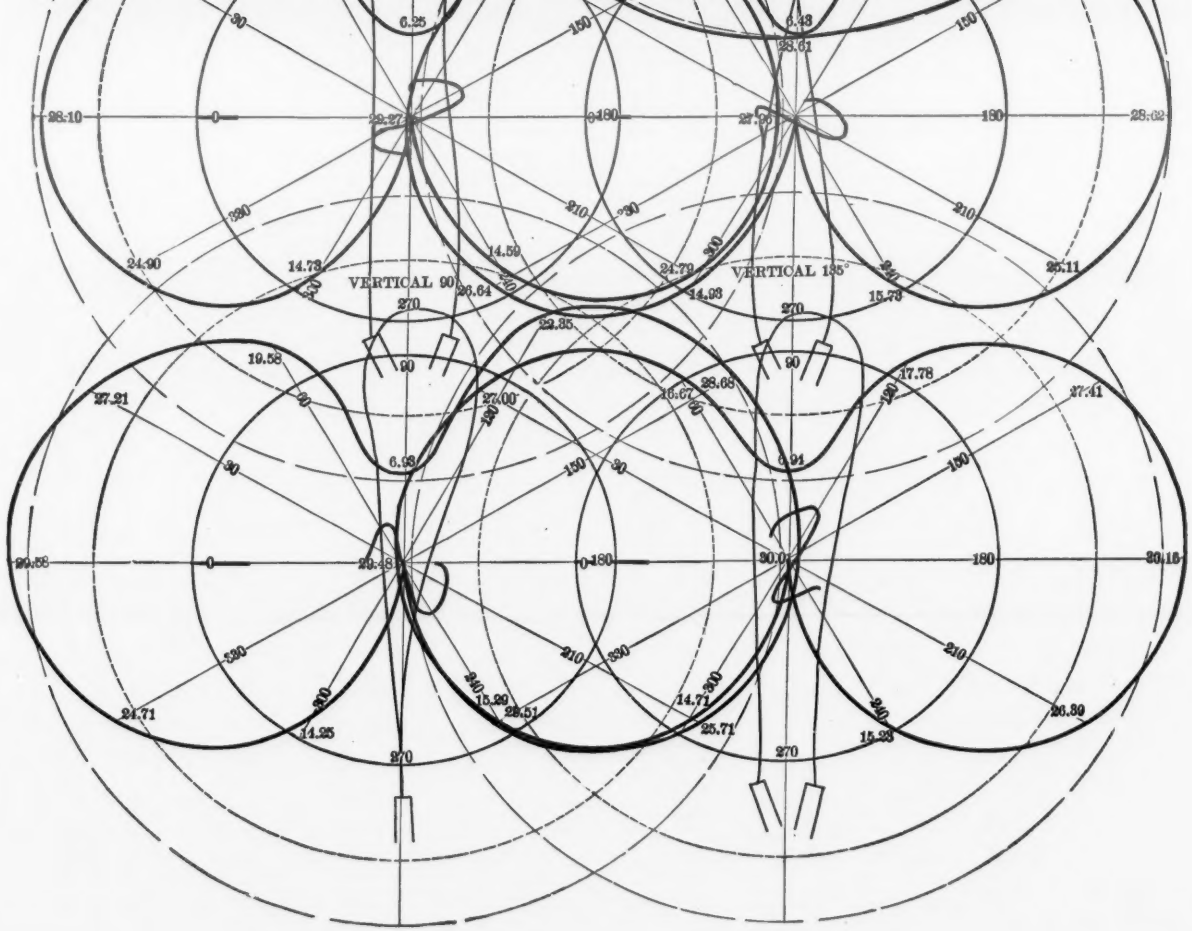
Full circle reduced from 3.2″ to 2.5″ in engraving.



Rated c. p. = full circle.
Mean sph. c. p. = dotted circle.
Mean hor. c. p. = dashed circle.
Section of filament = Circ.
Scale of c. p. = 10 c. p. to inch.

Full circle reduced from 3.2″ to 2.5″ in engraving.

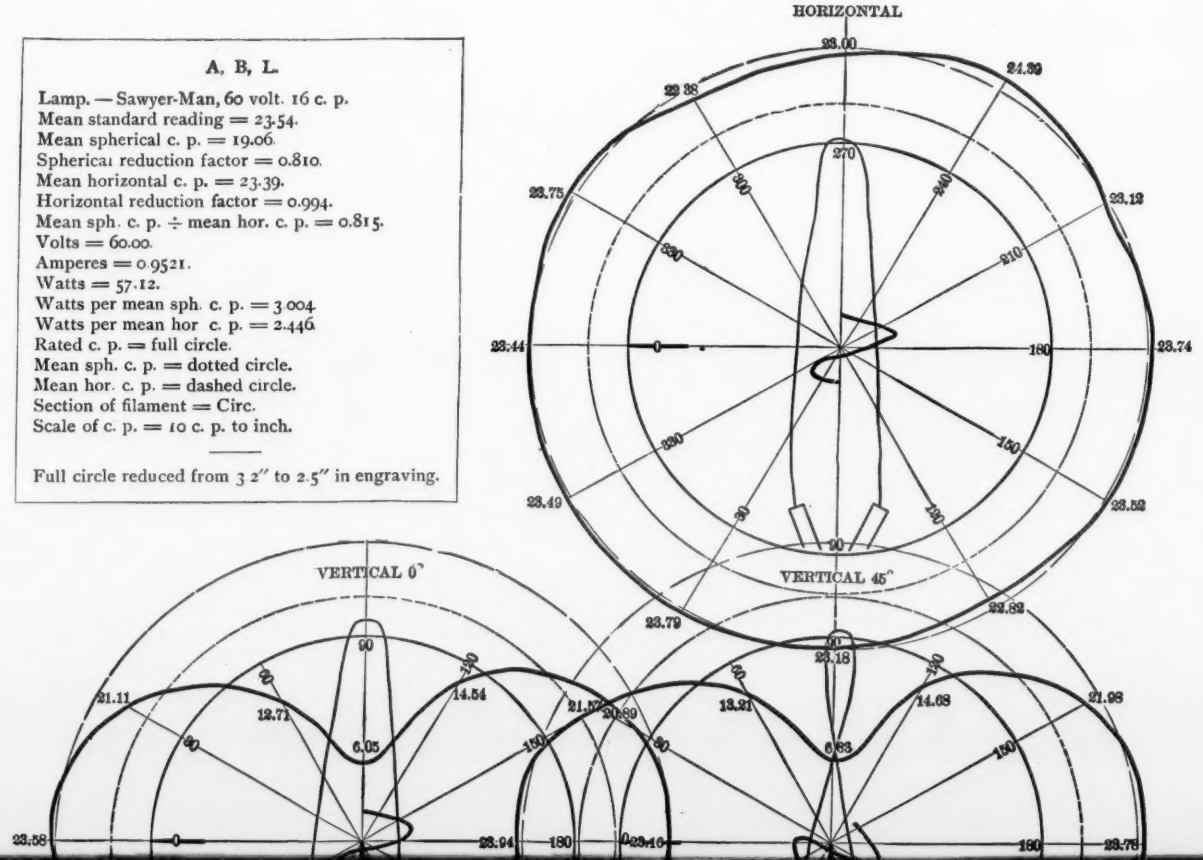



VERTICAL 90
VERTICAL 135
0
30
60
90
120
150
180
210
240
270
300
330
6.25
6.48
28.61
28.10
22.27
27.99
28.62
24.90
14.73
14.59
24.79
25.11
14.93
15.73
26.64
22.85
19.58
27.21
27.00
16.67
28.65
17.78
37.41
6.93
6.91
29.58
29.48
30.00
30.15
24.71
14.25
15.29
29.51
14.71
25.71
15.23
26.39

A, B, L.

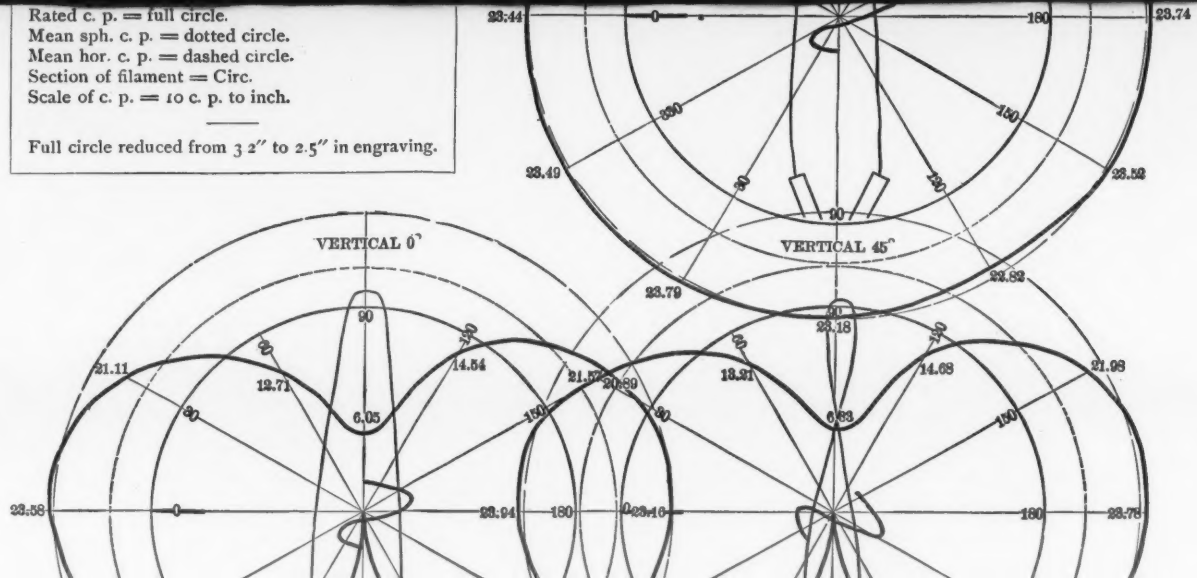
Lamp. — Sawyer-Man, 60 volt. 16 c. p.
Mean standard reading = 23.54.
Mean spherical c. p. = 19.06.
Spherical reduction factor = 0.810.
Mean horizontal c. p. = 23.39.
Horizontal reduction factor = 0.994.
Mean sph. c. p. ÷ mean hor. c. p. = 0.815.
Volts = 60.00.
Amperes = 0.9521.
Watts = 57.12.
Watts per mean sph. c. p. = 3.004.
Watts per mean hor c. p. = 2.446.
Rated c. p. = full circle.
Mean sph. c. p. = dotted circle.
Mean hor. c. p. = dashed circle.
Section of filament = Circ.
Scale of c. p. = 10 c. p. to inch.

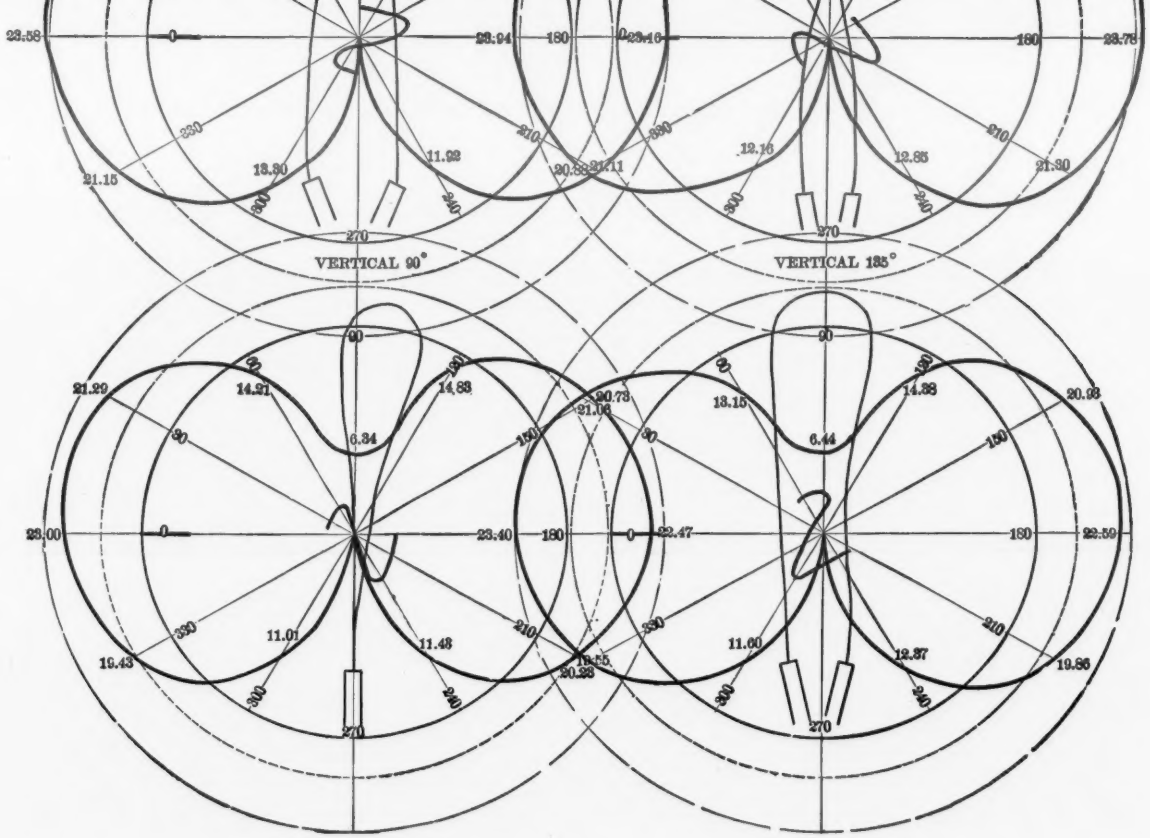
Full circle reduced from 3 2″ to 2.5″ in engraving.



Rated c. p. = full circle.
Mean sph. c. p. = dotted circle.
Mean hor. c. p. = dashed circle.
Section of filament = Circ.
Scale of c. p. = 10 c. p. to inch.

Full circle reduced from 3 2″ to 2.5″ in engraving.

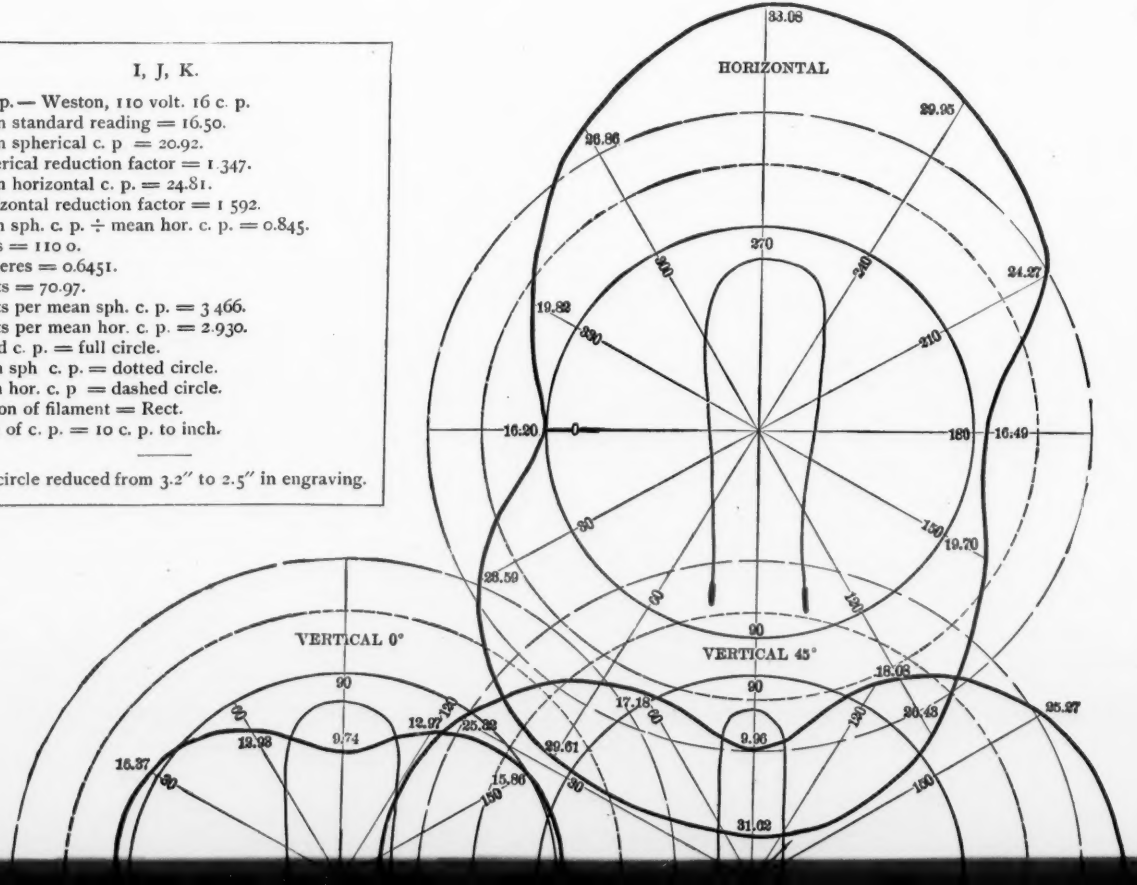



VERTICAL 90°
VERTICAL 135°

I, J, K.

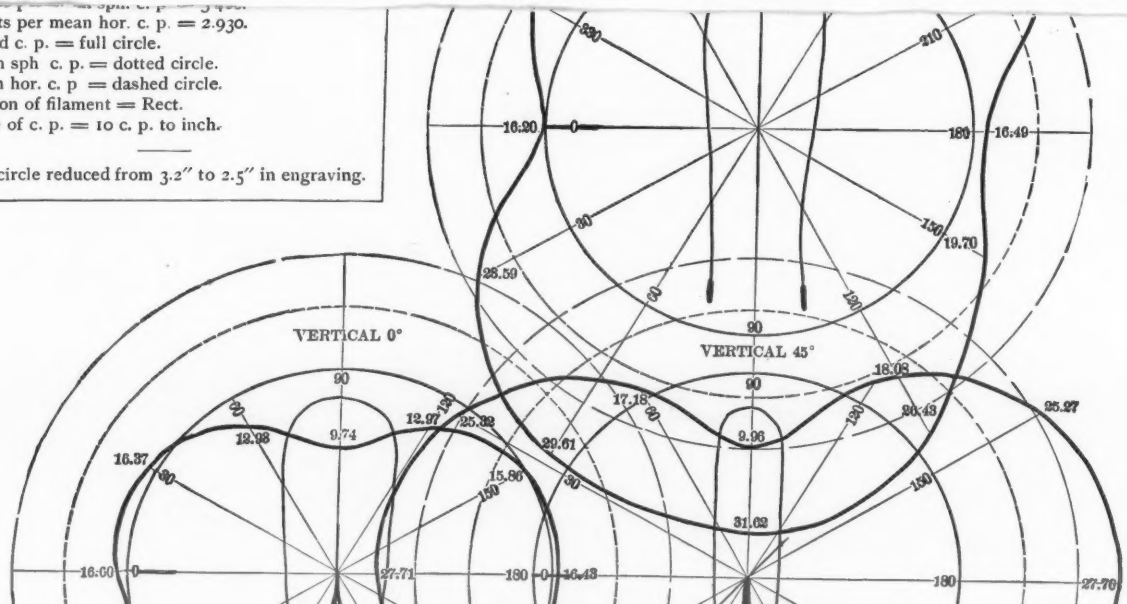
Lamp. — Weston, 110 volt. 16 c. p.
Mean standard reading = 16.50.
Mean spherical c. p = 20.92.
Spherical reduction factor = 1.347.
Mean horizontal c. p. = 24.81.
Horizontal reduction factor = 1 592.
Mean sph. c. p. ÷ mean hor. c. p. = 0.845.
Volts = 110 o.
Amperes = 0.6451.
Watts = 70.97.
Watts per mean sph. c. p. = 3 466.
Watts per mean hor. c. p. = 2.930.
Rated c. p. = full circle.
Mean sph c. p. = dotted circle.
Mean hor. c. p = dashed circle.
Section of filament = Rect.
Scale of c. p. = 10 c. p. to inch.

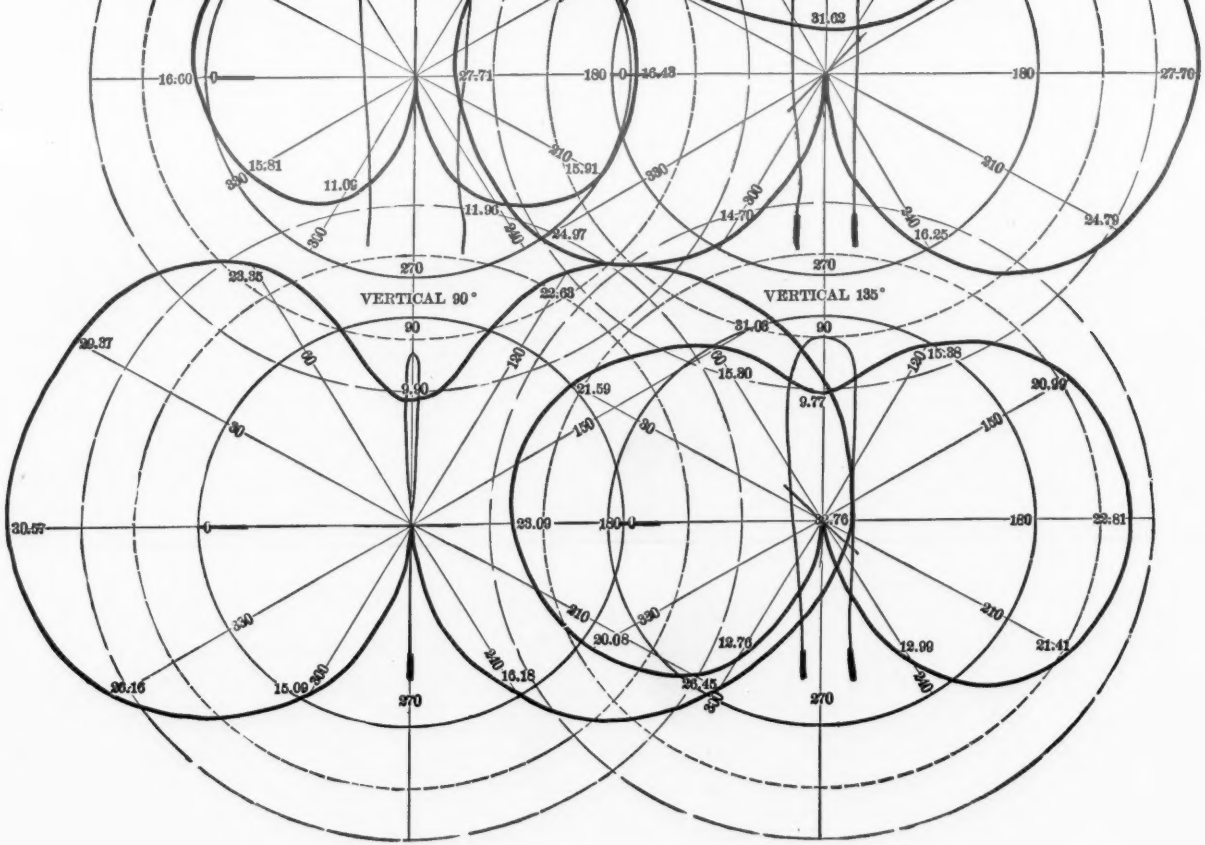
Full circle reduced from 3.2″ to 2.5″ in engraving.



Watts per mean hor. c. p. = 2.930.
Rated c. p. = full circle.
Mean sph c. p. = dotted circle.
Mean hor. c. p = dashed circle.
Section of filament = Rect.
Scale of c. p. = 10 c. p. to inch.

Full circle reduced from 3.2″ to 2.5″ in engraving.



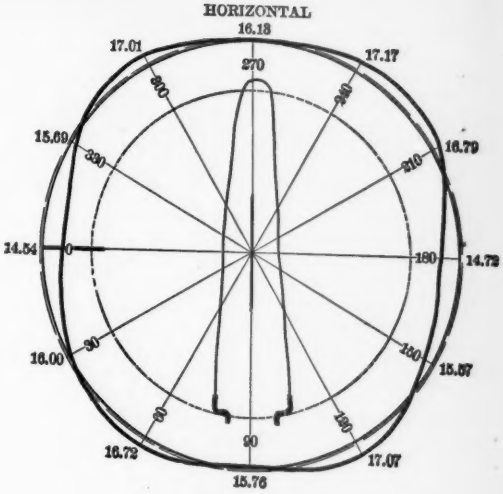

VERTICAL 90°
VERTICAL 135°
0
90
180
270
30
60
120
150
210
240
300
330
16.00
27.71
15.81
11.06
15.91
11.90
24.97
31.02
16.43
27.70
14.70
16.25
24.79
23.35
22.63
29.37
9.90
30.57
26.16
15.09
16.18
21.59
23.00
31.08
15.80
9.77
15.88
20.99
2.76
22.81
20.08
12.76
12.99
21.41
26.45

E, F, N.

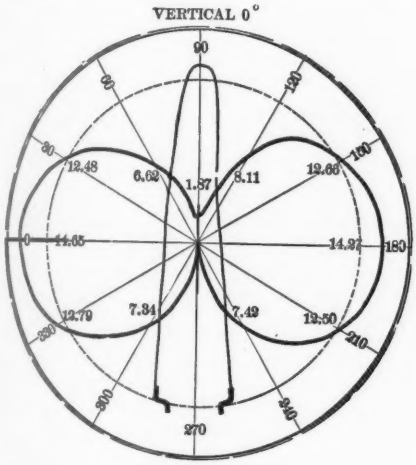
Lamp. — Edison new, 110 volt. 16 c. p. 3.1 Watts.
Mean standard reading = 14.57.
Mean spherical c. p. = 12.34.
Spherical reduction factor = 0.851.
Mean horizontal c. p. = 16.10.
Horizontal reduction factor = 1.111.
Mean sph. c. p. ÷ mean hor. c. p. = 0.767.
Volts = 110.0.
Amperes = 0.4552.
Watts = 50.07.
Watts per mean sph. c. p. = 4.070.
Watts per mean hor. c. p. = 3.120.
Rated c. p. = full circle.
Mean sph. c. p. = dotted circle.
Mean hor. c. p. = dashed circle.
Section of filament = Rect.
Scale of c. p. = 10 c. p. to inch.

Full circle reduced from 3.2″ to 2.5″ in engraving.

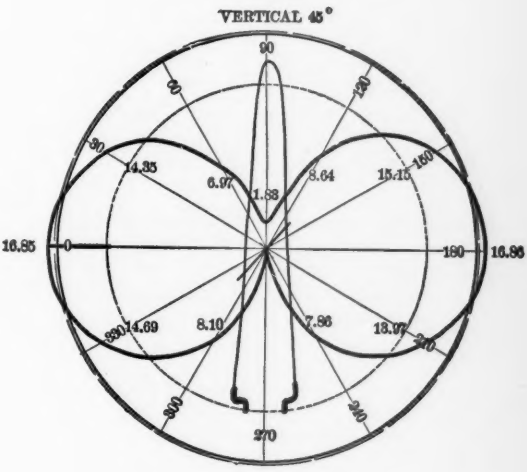
HORIZONTAL



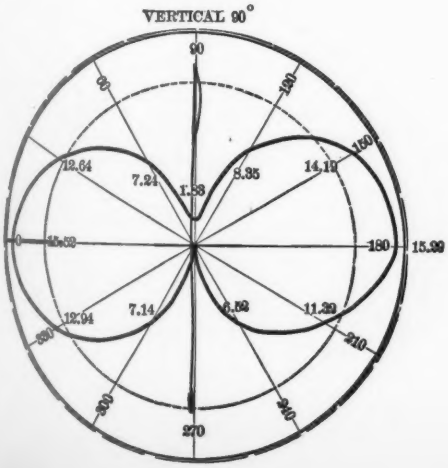
VERTICAL 0°



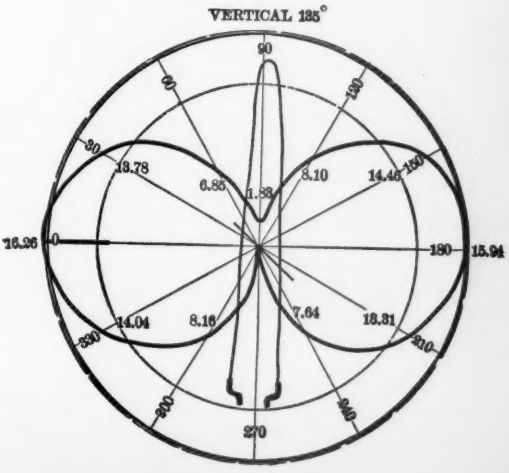
VERTICAL 45°



VERTICAL 90°



VERTICAL 135°

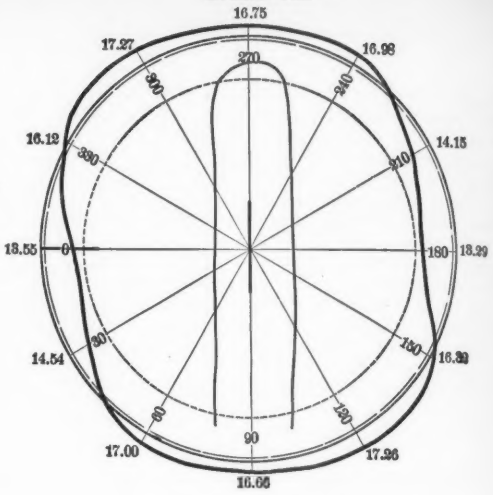


R, S, T.

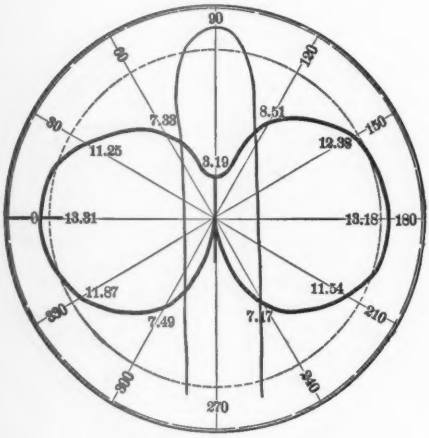
Lamp. — Edison, 93 volt. 16 c. p.
Mean standard reading = 13.38.
Mean spherical c. p. = 12.65.
Spherical reduction factor = 0.947.
Mean horizontal c. p. = 15.83.
Horizontal reduction factor = 1.185.
Mean sph. c. p. ÷ mean hor. c. p. = 0.800.
Volts = 93.00.
Amperes = 0.7240.
Watts = 67.33.
Watts per mean sph. c. p. = 5.325.
Watts per mean hor. c. p. = 4.259.
Rated c. p. = full circle.
Mean sph. c. p. = dotted circle.
Mean hor. c. p. = dashed circle.
Section of filament = Rect.
Scale of c. p. = 10 c. p. to inch.

Full circle reduced from 3.2″ to 2.5″ in engraving.

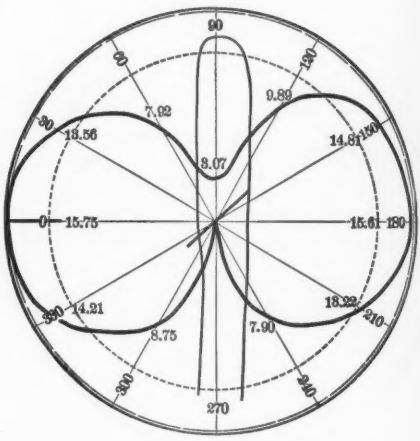
HORIZONTAL



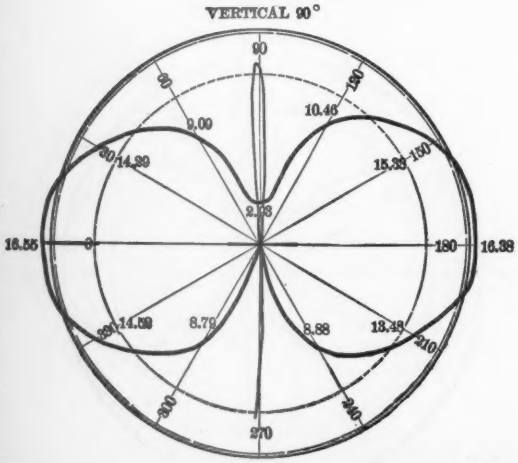
VERTICAL 0°



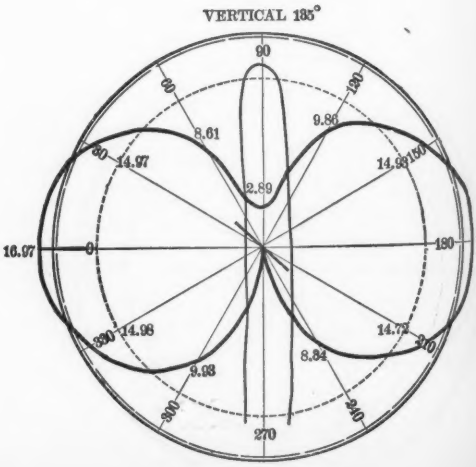
VERTICAL 45°



VERTICAL 90°



VERTICAL 135°

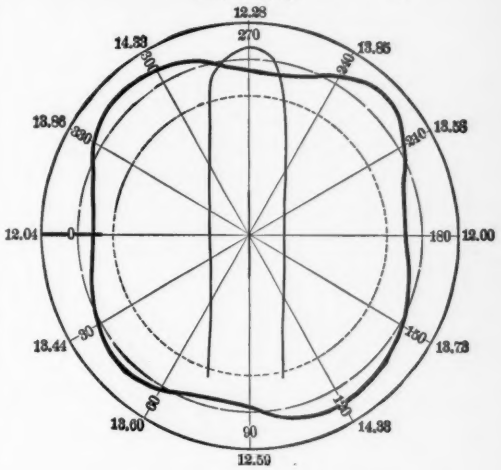


O, P, Q.

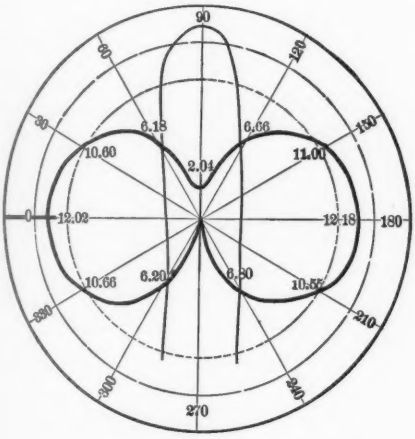
Lamp. — Edison, 85 volt. 16 c. p.
Mean standard reading = 12.06.
Mean spherical c. p. = 10.48.
Spherical reduction factor = 0.873.
Mean horizontal c. p. = 13.30.
Horizontal reduction factor = 1.108.
Mean sph. c. p. ÷ mean hor. c. p. = 0.789.
Volts = 85.00.
Amperes = 0.6200.
Watts = 52.70.
Watts per mean sph. c. p. = 5.044.
Watts per mean hor. c. p. = 3.976.
Rated c. p. = full circle.
Mean sph. c. p. = dotted circle.
Mean hor. c.p. = dashed circle.
Section of filament = Rect.
Scale of c. p. = 10 c. p. to inch.

Full circle reduced from 3.2″ to 2.5″ in engraving.

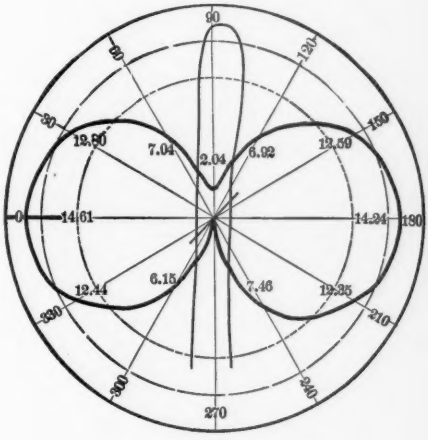
HORIZONTAL



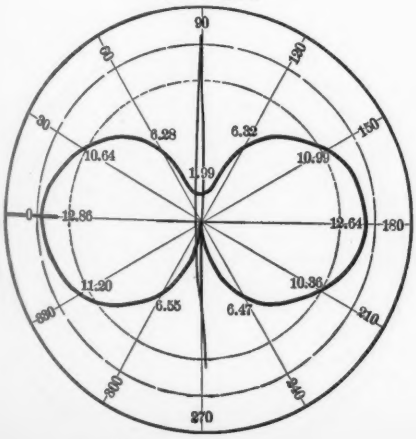
VERTICAL 0°



VERTICAL 45°



VERTICAL 90°



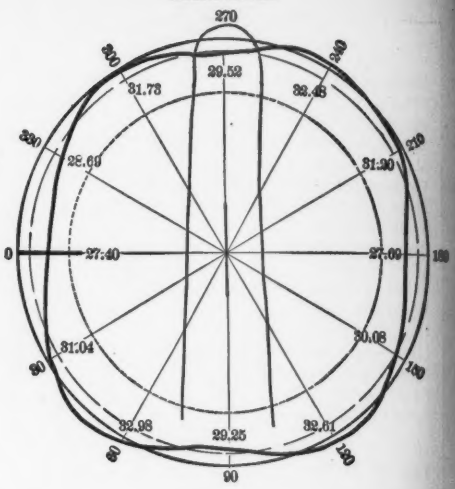
VERTICAL 135°

G, H.

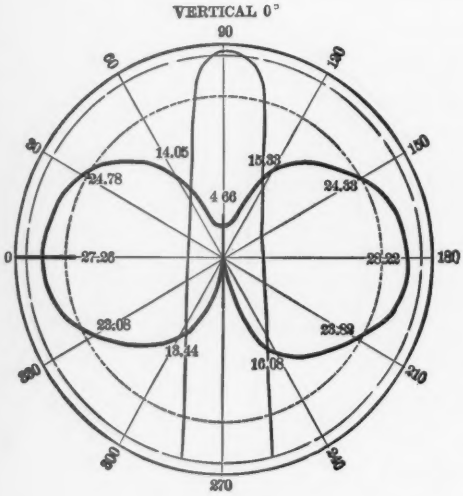
Lamp.—Edison, 110 volt. 32 c. p. 3.1.
Mean standard reading = 27.21.
Mean spherical c. p. = 24.08.
Spherical reduction factor = 0.890.
Mean horizontal c. p. = 30.39.
Horizontal reduction factor = 1.122.
Mean sph. c. p. ÷ mean hor. c. p. = 0.793.
Volts = 110
Amperes = 0.8507.
Watts = 93.58.
Watts per mean sph. c. p. = 3.889.
Watts per mean hor. c. p. = 3.081.
Rated c. p. = full circle.
Mean sph. c. p. = dotted circle.
Mean hor. c. p. = dashed circle.
Section of filament = Rect.
Scale of c. p. = 20 c. p. to inch.

Full circle reduced from 3.2″ to 2.5″ in engraving.

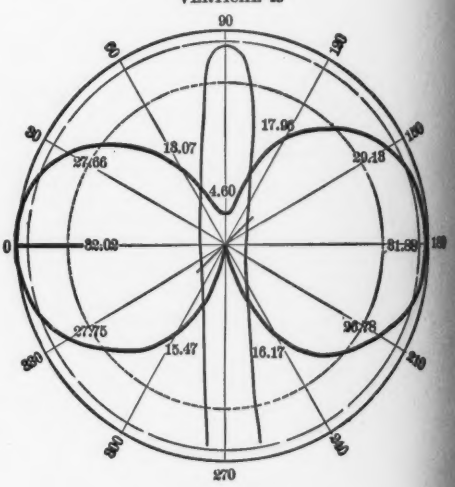
HORIZONTAL



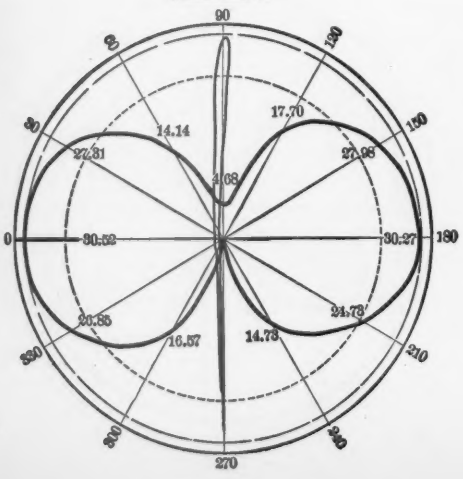
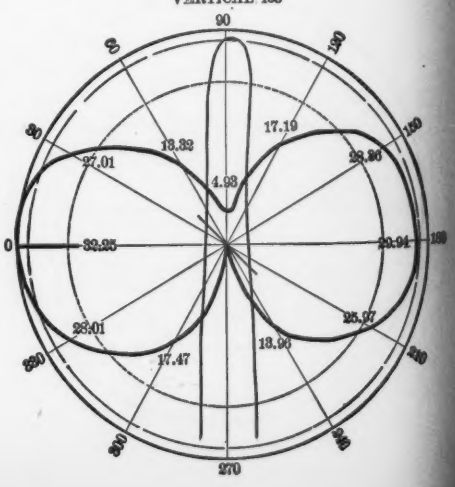
VERTICAL 0°



VERTICAL 45°



VERTICAL 90°



VERTICAL 135°